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All communications should be addressed to the Editor.

No. 95. NOVEMBER, 1918. VOL. XXII.

Notices of the Royal Aëronautical Society.

Popular Lecture.

The lecture announced for December 11th on "Civil Aerial Transport," by Mr. Claude Grahame-White, has been postponed in consequence of the proximity of the General Election. The lecture will be given on a date in January to be subsequently announced.

The Council.

At an Ordinary General Meeting of the Society, on November 20th, Rule IV.-6, was by resolution on the recommendation of the Council altered to read as follows:—

> "The Society shall be governed by the President, to be appointed as hereinbefore mentioned, and a Council of twenty voters, of whom at least one half shall be Fellows or Associate Fellows of the Society."

This involves an addition of four to the number of the Council. The vacancies thus created have been filled as follows:—

To Retire in 1919.—Lieut.-Col. T. R. Cave-Brown-Cave.
Lieut.-Col. Alan Burgoyne, M.P.

To Retire in 1920.—Brig.-Gen. Sir Capel Holden, F.R.S.
Major F. S. Southwell.

Erratum.

In the "Abstracts" for October (JOURNAL, p. 332), "Notes on Glue," the matter abstracted was attributed to the "Aerial Age Weekly." We now understand that the information originally appeared in "Aeronautics," and have much pleasure in making this correction.

Elections, November 28th, 1918.

Fellows.—Lieut.-Col. Moore-Brabazon, J. D. North, Major Hechstall Smith.

Associate Fellows.—Capt. E. E. Benest, G. H. Bechtel, J. Case, C. H. Guildford, A. E. Hayward, K. Lal, V. L. Le Cren, M. Lewin, D. F. Lucking,

Major A. McAlister, G. M. McCann, S. E. Neal, Capt. A. Payze, O. A. Price, P. T. Rawlings, L. J. H. Richards, S. T. A. Richards, Major R. V. Southwell, W. F. Spurr, M. M. Thomson, G. Watts, Capt. T. Worswick, B. Wilkins, Major S. V. Fill.

Members.—Capt. J. Clayton Young, Capt. W. C. Gibbings, R. B. Elliott, E. Birks, M. Boote, J. E. Heap, Maj.-Gen. J. G. Hearson, Major Steele Hutcheson, L. G. Maxton, E. J. Morris, Major C. K. Cochran Patrick, Sir Byron Peters, A. Ramsbottom, J. L. Roberts, L. E. Stamm, W. Stewart, H. H. C. Summers, L. E. Priest, Sir H. McMahon.

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Students.—S. Baldwin, F. Bardell, E. D. Bartlett, N. Beckett, P. R. Bradbrook, R. E. Brinton, C. G. Brown, E. C. Clark, H. W. Clark, S. Coutantinon, G. H. Dowty, A. Ellefon, H. Ghosh, A. Joshava, E. Lee, A. A. Lima, S. W. Luscher, C. Maggs, H. A. Mettam, J. S. Morgan, J. C. Naylor, F. H. Olerenshaw, C. H. Parsons, M. S. Rashid, G. R. Roberts, C. D. C. Rousseur, R. Sheen, F. H. Steers, H. Tasker, G. L. Thomas, F. A. Thompson, A. Warmisham, C. J. Wood, L. H. Robertson, D. Thomas, W. F. Garner, A. Presnall, C. Schwab, W. H. Simmons, T. Stevens, W. T. Keable, — Waddell, — Boling, J. K. Boyle, E. T. Burrow, W. F. Chappell, Geo. de M. Davis, G. Furneaux, G. E. Gardner, J. N. H. Gill, D. H. Hewitt, H. Hoyle, B. Levine, — McPherson, A. P. Mackin, T. W. Marsh, S. G. McMeckin, — Mathie, S. Morgan, M. C. Neville.

Foreign Members.—A. Tanakadate.

Papers and Lectures.

All contributors to the published work of the Society are requested to furnish with their contributions an abstract or synopsis of convenient length of the main conclusions of their work. This will be published with the paper and materially assist reference.

Appointments.

Mr. M. A. S. Riach, Fellow, has been appointed Consulting Engineer to the Department of Munitions Inventions, Ministry of Munitions of War.

STRESS OPTICAL EXPERIMENTS.

BY MAJOR A. R. LOW, R.A.F.

(1) **Elementary Account of Stress Optical Method.**

(2) **Description of Model and Apparatus.**

(3) **Examples of Optical Observations.**

(4) **Comparison of Results obtained from:—**
- (*a*) Optical observations.
- (*b*) Calculation by the method of C.I.M.9.
- (*c*) Observations of deflection.

(5) **Appendix.**
- (*a*) Details of calculations by C.I.M.9.
- (*b*) Calculations of point of inflection.
- (*c*) Tabulated observations of deflections.
- (*d*) Tabulated optical observations.

SECTION No. 1.

BIBLIOGRAPHY OF RESEARCH ON STRESS OPTICAL EFFECTS.

A.—Physical Theory.

1. Fresnel, "Annales de Chemie et de Physique," Vol. XX.
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7. F. Pockels, "Uber die Aendering des Optischen Verhaltens Verschiedener Glaeser Durch Elastische Deformation," Ann-d-Physik, 1902, Ser. 4, Vol. XI., Part 6.
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"Phil. Trans.," Series A, Vol. CCVII., pp. 263-306 (1907).
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B.—Application to Elastic Theory.

Clerk Maxwell's paper above cited (4).
9. Prof. Carus Wilson, "Phil. Mag.," Ser. 5, Dec., 1891.
10. E. G. Coker, Institution of Naval Architects, April 7th, 1911.
11. L. N. G. Filon, "Phil. Mag.," Ser. 6, Jan., 1912.
12. E. G. Coker, "Proc. Inst. Mech. Engineers," 10th Feb., 1913.
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SECTION No. 1.

NOTE ON THE DETERMINATION OF STRESS BY OPTICAL METHODS.

(1) Historical.

Sir David Brewster in 1816 discovered that an isotropic transparent solid, such as glass, behaves as a temporary crystal under stress, and when examined in the polariscope between crossed Nicols exhibits the characteristic colours of crystalline plates.

Since Brewster's day this property has been studied by a number of observers. Clerk Maxwell showed that isinglass jelly would show the colours under stress when in its soft state, and retained them, more or less permanently, when allowed to harden under strain. To him is due the first attempt to apply this effect to the exploration of the stress system in the plane of a strained plate; experimental investigations of this nature were afterwards carried out by Carus Wilson, by Major Filon, and by Prof. E. G. Coker, F.R.S.

Neither glass, however, nor isinglass jelly forms a suitable material for the investigation by this means of stresses in engineering structures. Glass does not lend itself readily to the construction of such models as regards shape and jointing. Isinglass jelly is altogether too soft. Prof. Coker, however, discovered that celluloid, or more properly, xylonite, possesses this stress optical property in a very high degree. This substance is easily worked and cut to any required shape, and will take the necessary fittings without being damaged, and the method by this means becomes a practical one from the engineering standpoint.

(2) Elementary Theory.

An elementary theory can be given as follows:—Consider a rectangular block of transparent material, Fig. 1, Plate 613, under uniform tensions (P), parallel to one set of edges and (Q) parallel to another set of edges.

Let light be passed through the material in a direction perpendicular to both stresses "P" and "Q." Then it is found that the light, on entering the material, is broken up into two portions. One is polarised in the direction of the stress "P," the other in the direction of the stress "Q."

These two light waves travel through the material at a different rate, so that, on emergence, one of them is retarded with respect to the other. If we call "r" the relative retardation, then it is found that

$$"r" = Ca\,(P - Q)$$

where "a" equals the thickness of the material traversed, and "C" is a coefficient depending only on the nature of the material and the wave length of the light.

So far the most recent investigations confirm the accuracy of the above law up to the highest stress that the material can bear. This is certainly the case as regards glass. As regards xylonite, it has not so far been possible to investigate the law with the same order of accuracy, but what investigations have been made confirm the rule that the relative retardation is strictly proportional to the difference of the two stresses.

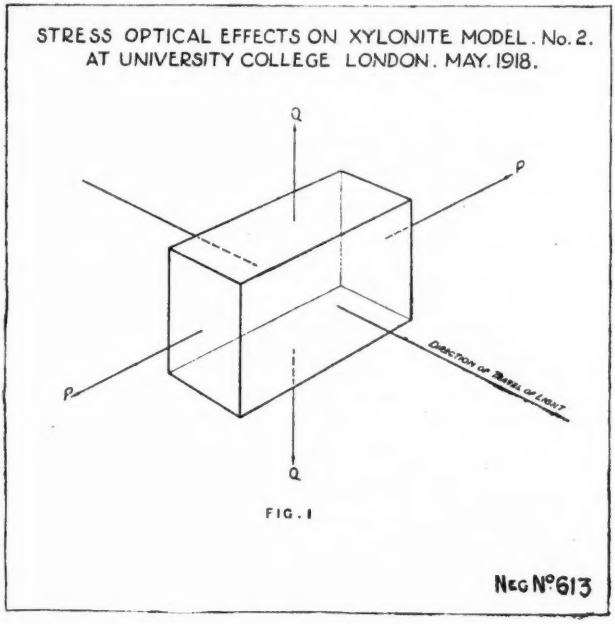
It is important to note that the relative retardation is proportional in every case to the difference of the *stresses*, and not to the difference of the *strains*. Thus the method will not lead to a determination of the strain, or curvature, unless the material is *not* strained beyond the elastic limit, in which case the stress is proportional to the strain. On the other hand, a material may have bad permanent *strain*, but unless this is accompanied by a corresponding permanent internal *stress*, there is little or no optical effect. The method thus provides a *direct determination* of the actual tensions and pressures occurring, and

enables us to explore the material dynamically—whereas any method of deflections, such as must be used with a model of opaque material, only gives us the visible strains from which the stresses are inferred by a process which lacks validity so soon as the elastic limit is passed.

Returning to the consideration of the light emerging from the block, it appears that if the relative retardation of the two waves is a whole number of wave lengths, they will emerge in the same phase in which they entered, and, on re-combining, the effect will be the same as if the block had not been present.

Now a Nicol prism is a block of Iceland spar, which only transmits light polarised in a particular aximuth which is called the axis of the Nicol prism.

If then two Nicol prisms are placed one behind the other with the axes perpendicular, the second cuts off all the light which is transmitted by the first, and on looking into the second prism the field is dark.



If, however, a crystalline plate, or a piece of xylonite under stress be now introduced between the Nicols, the light is in general restored when the directions of stress are different from the axes of the Nicols, the light transmitted by the first prism being depolarised; but if for any given kind of homogeneous light the stressed xylonite produces a relative retardation of a whole number of wave lengths we have seen its presence does not affect the character of the transmitted light. Thus, light of this particular colour will be extinguished in the field.

(3) Changes in a Uniform Field as Stress Increases.

Consider now the changes in the field when the stress difference $(P - Q)$ is steadily increased from zero.

At first there is no retardation and the field is dark. For a small stress all colours will be restored and the field will be white.

As the stress increases a time will come when one of the colours of the visible spectrum will again be extinguished. This will occur when

$$\lambda = Ca\ (P - Q) \text{ or } a\ (P - Q) = \lambda / C,$$

λ being the wave length of the colour in question. Now it has been found that C varies somewhat between the extreme red and the extreme violet, but not more than about 10% to 20% of the whole. The result is that λ/C always increases as λ increases.

Thus, the first colour to be extinguished as $(P - Q)$ increases is that of lowest λ, that is the violet and blue. The remaining colours give an orange which deepens to a red, and this changes somewhat sharply, to a blue, as we go through the so-called "tint of passage" which corresponds to the extinction of the bright yellow rays.

As we further increase the stresses, white reappears, then a pinky red, followed by a second order tint of passage, itself followed by a greenish blue. The series of colours are then repeated, the reds approximating at each order more and more to a pale pink, and the blues to a pale green.

If, therefore, we construct an exact scale of colours we could invert the process, and from the colour in the field at any given moment, deduce the actual stress difference to which the material is subjected.

In practice this would be a difficult process, and the risk of confusing colours of different orders would be considerable. Where, however, a certain indication can be obtained of the order of colour dealt with, this method, as we shall see, can be very usefully employed.

(4) Null Method of Measurement.

Another method, however, removes this difficulty and enables the stress to be determined by a null method.

Let two blocks—A and B—of the same material and the same thickness be employed, and placed one behind the other with their edges parallel. Fig. 2, Plate 614. Let stress P and Q be applied to the blocks A and B as before with this difference, that in those directions in which the stresses on Block A are P and Q, the stresses on Block B are Q and P respectively.

Two such blocks under stress corresponding stresses being at right angles, will be spoken of as crossed. To fix ideas suppose that in the block A the stress P is applied horizontally, and the stress Q vertically. Then in the block B, P is applied vertically and Q horizontally.

Now the light traversing either beam is broken up into a horizontally polarised and a vertically polarised wave, and the conditions of travel of these two waves are interchanged in A and B. Thus if the horizontally polarised ray be accelerated with regard to the vertically polarised ray by an amount "r" after traversing A, the vertically polarised ray will be accelerated with regard to the horizontally polarised ray by the same amount "r" after traversing B, the net acceleration or retardation after traversing both A and B being zero. We thus get a black field if the two blocks are placed between crossed Nicols.

We may therefore ascertain the stress difference in a given specimen of material (the stresses acting in known directions) by placing in front of it a test piece of the same material and same thickness to which we apply known stresses in the same directions until we find that the field becomes black. When this is the case, the stress difference in the test piece and specimen are equal in magnitude and opposite in sign.

(5) Appearances in a Non-Uniform Field. Neutral, Isochromatic and Isoclinic Lines.

Let us now pass to the case of the appearances presented when a flat slab or plate under stress in its own plane is examined in this way between crossed Nicols.

In such a slab the stresses will vary from point to point. At any given point, however, the stress system can be reduced to two principal normal stresses (tensions or pressures) in directions at right angles—these directions being known as the principal axes of stress at the point. Every point for which the principal stress difference is zero will appear black in the field and the locus of such points forms a black band or " neutral line." Generally on either side of the neutral line is a white area, in which the principal stress difference is slight. If the applied stress is sufficiently large on going outwards from the neutral line a rainbow band is met, beginning with orange and going into red tint of passage and blue. This is the " first order " coloured band. Beyond it will be a yellowish space, and a " second order " coloured band, reddish towards the neutral line and green away from it.

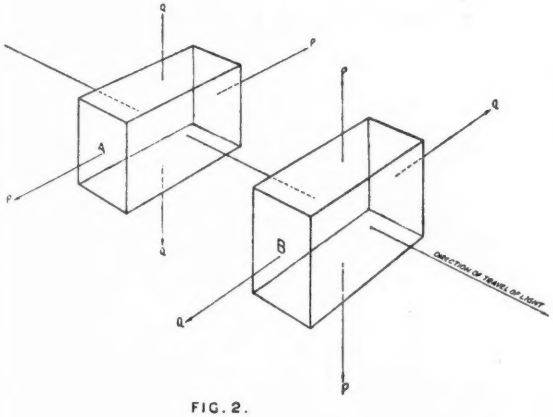


FIG. 2.

STRESS OPTICAL EFFECTS ON XYLONITE MODEL. No. 2.
AT UNIVERSITY COLLEGE. LONDON. MAY. 1918.
NEG N°614

These bands are called " isochromatic " lines, or lines of equal colour. Along any one isochromatic line the principal stress difference in the material is constant in magnitude. A mapping of the isochromatic lines therefore gives a picture of the distribution of stress difference throughout the material. As yield and rupture of many materials depends largely upon the value of the stress difference, such a picture gives immediate information as to the dangerous areas or fail points. These will necessarily be those points where the colour bands of highest order make their appearance as the load is increased.

The neutral line and the isochromatic lines, however, are not the only bands visible in the field. So far, in the previous discussion of the appearances presented by a uniformly loaded block it has been assumed that the polarising axes of the two Nicols were not parallel to the directions of stress. On that assumption we have seen light was in general restored.

If, however, it happens that the polarising axes of the Nicols are parallel to the directions of stress, the light is never restored, for then, of the two waves in the stressed material, one coincides with the wave transmitted by the first Nicol, and the other is absent. The stressed material does not therefore depolarise the light, and the second Nicol stops it entirely.

It follows, then, that all points of the slab at which the directions of the principal axes of stress are parallel to the polarising axes of the Nicols will appear black in the field, hence one or more black bands or brushes corresponding to the locus of such points. Lines of this kind are called " isoclinic lines," or lines of equal inclination.

If the Nicols be rotated together, the isoclinic lines move in the field, but the isochromatic lines remain fixed. If the applied loads be increased in any given proportion, the distribution remaining the same, the isochromatic lines crowd in upon the neutral line. The neutral line and the isoclinic lines remain fixed.

The isoclinic lines are most useful when we do not know beforehand from other considerations the directions of the principal stresses at a given point. These directions can then be easily determined by rotating the Nicols until the visible

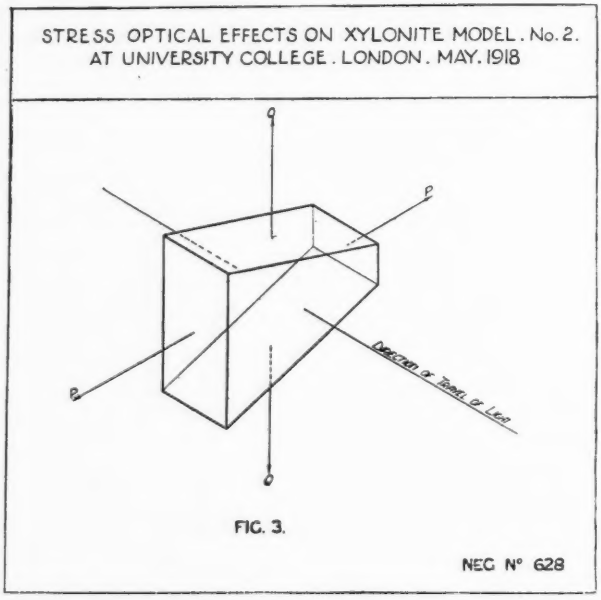


FIG. 3.

isoclinic line passes through the point in question. The position of the polarising axes of the Nicols then gives the solution of the problem, and enables us to set our test pieces at the correct angle if we use the null method of measuring the stress difference.

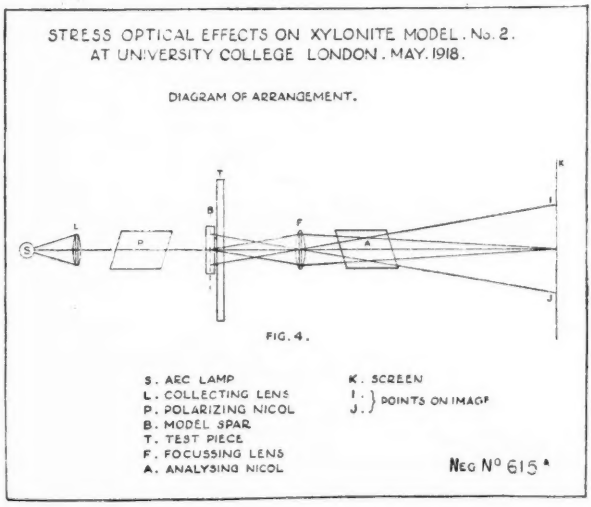
(6) Simplifications in the Case of a Bar Under Flexure.

On the other hand, in many cases the principal axes of stress can be predicted and thus much time and labour can be saved. For example, we know that in the case of a flat strip bent in its own plane by flexure without shear, the principal axes of stress are parallel and perpendicular to the edge of the strip. In the experiments here described, the object was to explore the stresses in a horizontal bar under flexure, and although it was known that the flexure was not indeed without shear, yet such shear would in general be small compared with the axial tensions, or pressures, in the bar; at any rate, for points not too close to the neutral axes of the beam, so that it would be safe to assume that principal axes of stress were horizontal and vertical.

A further simplification can also be made; in a bar under flexure the transverse stress is always zero or very small, at any rate in those parts where the bar is free —accordingly in calculating the stress difference (horizontal-vertical) it was allowable to put the vertical stress = 0, so that the principal stress difference was taken as the horizontal stress in the bar.

(7) Test Piece.

The comparison test piece consisted of a piece of xylonite of the same material and thickness of the specimen to be studied, but of variable breadth, so that its section tapered to a narrow neck (Fig. 3, Plate 628). The object of this was to give a continuous scale of tension or pressure (from .4 to 1 of the stress at the neck) enabling adjustments to be made without altering the total pull or thrust on the test piece. This latter was applied by means of a screw fitted in a circular



holding frame—the stress at the neck could thus be read off on a graduated thimble in accordance with a careful independent calibration.

(8) Optical Arrangements—Error of Obliquity.

The optical arrangements for the first set of experiments were as shown diagrammatically in Fig. 4, Plate 615. Light from an arc lamp S, gathered by a collecting lens L, and after passing through a polarising Nicol P, illuminating the bar B (shown in section in Fig. 4, Plate 615).

The vertical mid-section of the bar B is focussed by means of a lens F upon a screen K, the light passing through an analysing Nicol A (crossed with P) between F and K.

The object of focussing the median plane of the bar B, instead of its nearer or further face, is to eliminate a source of error due to the slight obliquity of the bulk of rays which traverse B. For we know that in a bent bar the stress varies in a cross-section as the distance from the neutral axis. Hence, if a ray traverses the bar horizontally the stress is the same throughout the passage, and the formula for the relative retardation,

$$r = aCP$$

can be applied directly.

But in a ray such as ACD, Fig. 5, Plate 616, the stress in the part SD of the path is greater than the stress at C, and the stress in the part AC is less than the stress at C. The retardation $= Cx$ total thickness traversed $\times$ mean stress across path. But this mean stress is, in this case, the stress at C. Hence, all rays through C have the same mean stress and therefore the same retardation, for a slight obliquity makes no sensible difference in the total thickness traversed.

If then we focus on the median plane of the bar, all the rays which come to the same point of the screen have the same retardation, namely, that due to the stress at that point of the median plane from which they come. We thus get the correct isochromatic lines for that median plane.

STRESS OPTICAL EFFECTS ON XYLONITE MODEL No 2.
AT UNIVERSITY COLLEGE. LONDON. MAY. 1918.

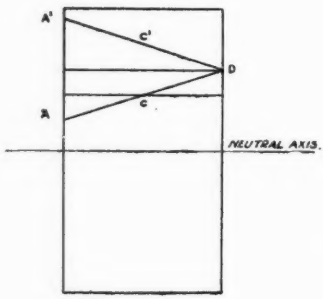


FIG. 5.

SECTION OF MODEL SPAR SHEWING RAYS
PASSING THROUGH A POINT ON A SURFACE

NEG N°616A

If, however, we were to focus on any other vertical plane, say one of the faces of the bar, then the various rays through a point D (Fig. 5, Plate 616) have different middle points CC, and therefore different retardations. The colours on the screen will therefore overlap and blur to a certain extent and accuracy will be impaired.

The position of the lens F was adjusted so as to give always the same magnification for the image, namely, the bar appeared on the screen as 12in. high. Points I, J (Fig. 4, Plate 615) on the image 2in. from the extreme edge on the tension and on the compression side were selected as suitable points at which to determine the stresses.

These points had to be taken in preference to points close to the extreme edge because it was found that xylonite as it dries forms an outside "skin" which is under considerable initial stress, even when no load is applied to the bar, and on this account the colour bands are seriously upset by this initial stress in the neighbourhood of the edge, which is therefore best avoided when accuracy is required.

(9) Method of Observation Errors of Parallax.

The test piece was then placed with its length vertical and as close to the specimen as possible. The effect was to shift the neutral line from the centre line of the bar up or down through a varying amount, corresponding to the stress in the test piece. By adjusting the total pull or thrust in the test piece and also moving it slightly up and down, it was always possible to bring the black band with its centre on one of the points I, J. The stress in the test piece was then read.

Now let P be the stress in the specimen due to the loading, P_o the permanent stress difference in the specimen at the point observed, and let T, T_o be corresponding quantities in the test piece. In practice it was found that the permanent stress (which was small) had in general its axes roughly parallel and perpendicular to the length of the bar—and the same held good for the test piece.

We can therefore simply add P to P_o and T to T_o to get the total effect and we get

$$P + P_o = T + T_o$$

Another set of readings taken with the framework unloaded, so the $P = o$. If T is then found to be T^1

$$P_o = T^1 - T_o$$

Subtracting $P = T - T^1$ gives a result for the stress due to the loading, which should be fairly independent of the permanent stresses in beam and test piece. To get the best possible results the test piece should have been changed from tension to compression when passing from I to J (or conversely) as it is found that a number of causes of error (and in particular the possibility that the stress optical coefficient C may be slightly different for large pressures and large tensions) are eliminated if we take care always to have the bar and specimen at right angles, so that at the points examined the two are always under stresses of the same name.

It was not, however, found convenient to do this. With the high loads employed a considerable amount of "creep" showed itself in the material. This "creep" itself modified the applied stress system, by increasing the part of the bending moment due to thrust and in this way the stress in the material showed progressive increase with time. It was therefore important to make all measurements at I and J as nearly simultaneous as possible, and the time taken in readjusting the test piece from tension to compression was prohibitive. The method employed then was to use the test piece in tension, only placing it at right angles to the specimen where tensions were to be measured, but parallel to it to measure pressures.

A little difficulty was experienced owing to the fact that the test piece and bar could not be in focus together, so that the graduations of the test piece were always somewhat blurred. This difficulty, however, was not such as to seriously affect the observations.

A certain amount of overlapping of colours must also necessarily occur owing to rays from the same point of the median plane of the specimen passing through different parts of the test piece. This "parallax" error undoubtedly must have slightly impaired the definition, and it may in addition have introduced a small systematic error.

In later observations all these troubles due to parallax were removed by separating the specimen and test piece, and introducing between them a lens, so that the median planes of the specimen and test piece were focussed upon each other and the two were finally focussed together upon the screen.

(10) General Accuracy of Optical Observations of Stress.

Some idea of the accuracy with which such observations of stress could be taken with xylonite was obtained by using a specimen strained under flexure with-

out strain, the bending moment on which was exactly known. In this case the stress in the specimen can be calculated exactly. By measuring it independently with the test piece, we can form an estimate of the errors made by this process.

The measurements were taken with test piece and specimen crossed and parallel, and also with the specimen in tension and with the specimen in compression.

By taking means of the four measurements the permanent stresses were eliminated, the same point of the specimen and of the test piece having been used in all four.

Altogether the results showed a mean probable error according to the following table :—

Range of stress.	No. of observations.	Mean probable proportional error.
100-500 lbs.	95	.057 (2)
500-1000	103	.032 (3)
1000-1500	60	.031 (4)
1500-2200	24	.045 (1)
100-2200	287	28.5 lbs.

SECTION No. 2.

ARRANGEMENT OF APPARATUS.

Fig. 6, Plate 374, shows the model with xylonite spars, steel struts and bracing wires, attached to a vertical post.

Fig. 7, Plate 371, shows the model with a guide frame and guide pieces to prevent lateral buckling and the back of the camera used in photographing the optical effects. The two weights are attached to horizontal wires which serve as base lines for measuring deflections.

Fig. 8, Plate 372, shows side view of the installation showing particularly the position of the optical apparatus. From left to right are placed the camera, the second Nicol, a collecting lens, the model, the first Nicol, concealed behind the trestle, and the arc lamp and lantern supplying a source of light and a collecting lens.

Fig. 9, Plate 373, gives a perspective view of the whole apparatus before the load is applied.

Fig. 10, Plate 375, shows the method of loading, the curvature of the spar, and the deflections of the nodes from the horizontal cross wires are easily visible to the eye.

Fig 11, Plate 376, shows the test piece actually used, as described in Section 1, paragraph 7.

Fig. 12, Plate 377, shows the whole apparatus with the test piece in tension crossing the model spar and placed as close as possible to it, the beam of the polarised light being focussed on the median plane of the model spar. It is therefore not focussed on the median plane of the test piece, and a certain lack of clearness in the definition of the dark band neutralised by the test piece is accordingly produced. This effect is kept as small as possible by placing the test piece close up to the model spar. But a better arrangement suggested by Major Filon and actually tried on another model is obtained by interposing another lens between model spar and test piece at such a distance that the beam of light is again focussed on the median plane of the test piece as well as on the median plane of the model spar. In the present experiments the method of placing the test piece close to the model spar was used throughout, and it is considered that the blurring of the image inevitable in this method did not introduce any serious discrepancy.

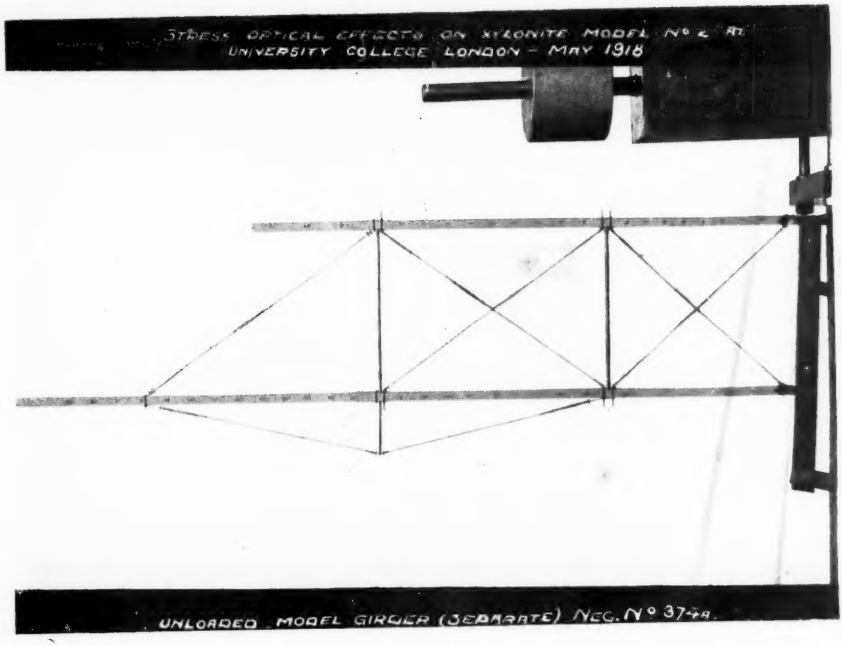

STRESS OPTICAL EFFECTS ON XYLONITE MODEL No 2 AT
UNIVERSITY COLLEGE LONDON - MAY 1918
UNLOADED MODEL GIRDER (SEPARATE) NEG. N° 37-A.

FIG. 6.

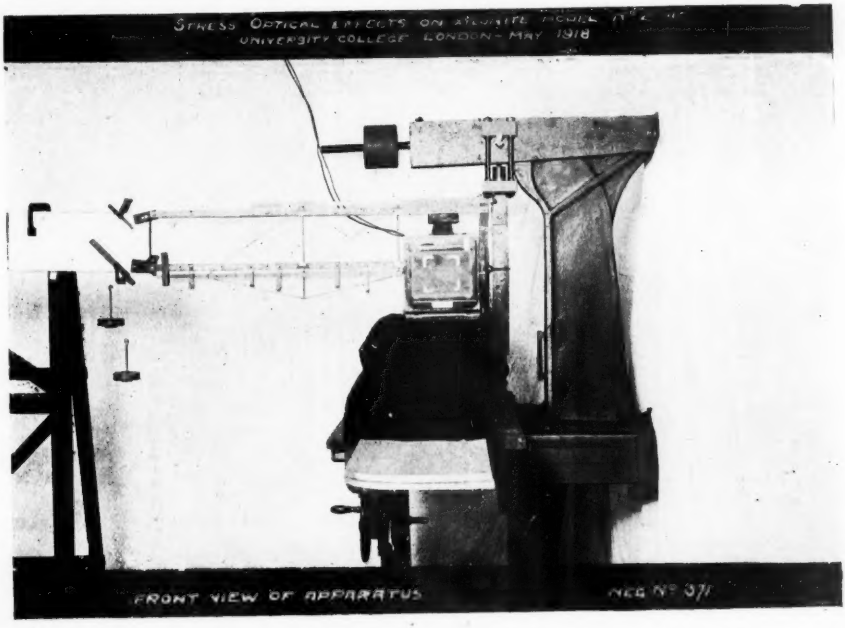

STRESS OPTICAL EFFECTS ON XYLONITE MODEL
UNIVERSITY COLLEGE LONDON - MAY 1918
FRONT VIEW OF APPARATUS
NEG N° 371

FIG. 7.

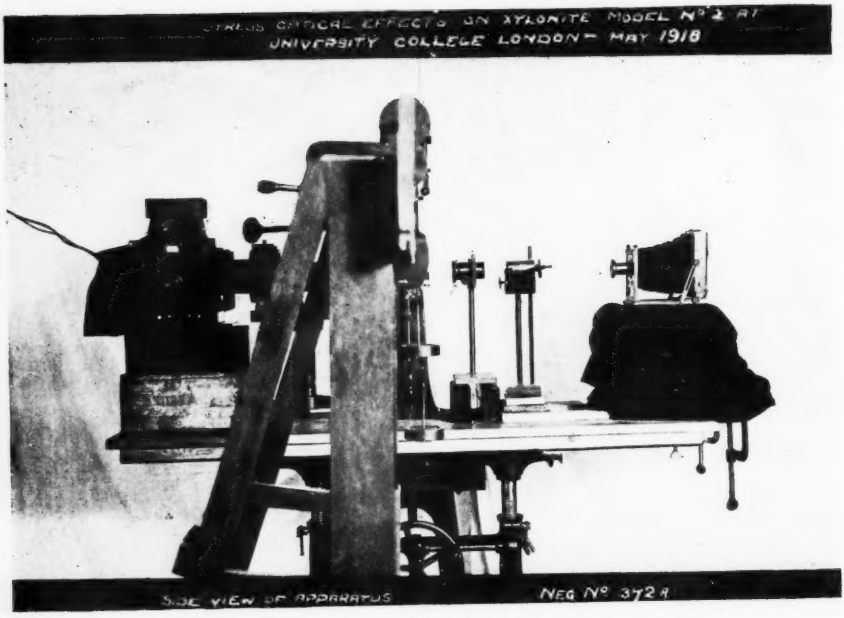

STRESS OPTICAL EFFECTS ON XYLONITE MODEL N° 2 AT
UNIVERSITY COLLEGE LONDON - MAY 1918
SIDE VIEW OF APPARATUS
NEG N° 372 A

FIG. 8.

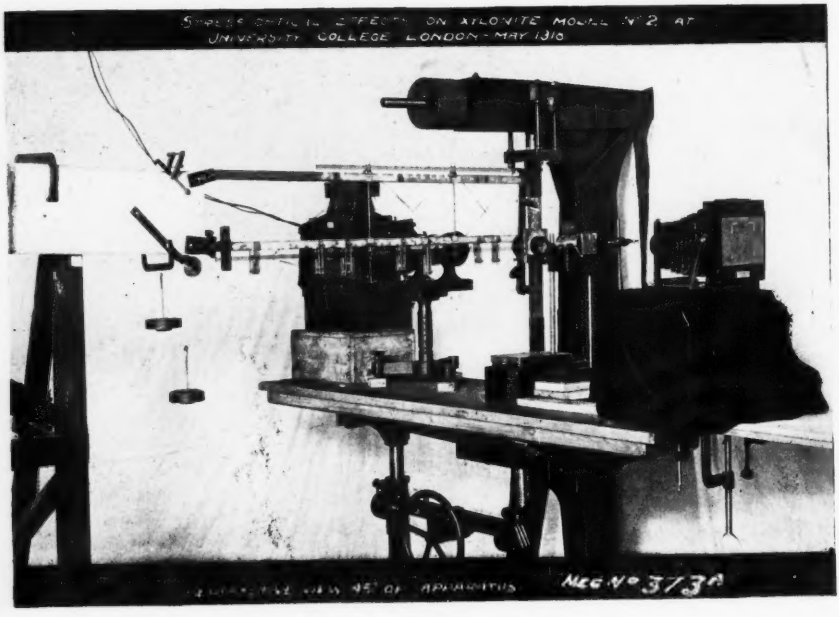

UNIVERSITY COLLEGE LONDON - MAY 1918
NEG N° 373A

FIG. 9.

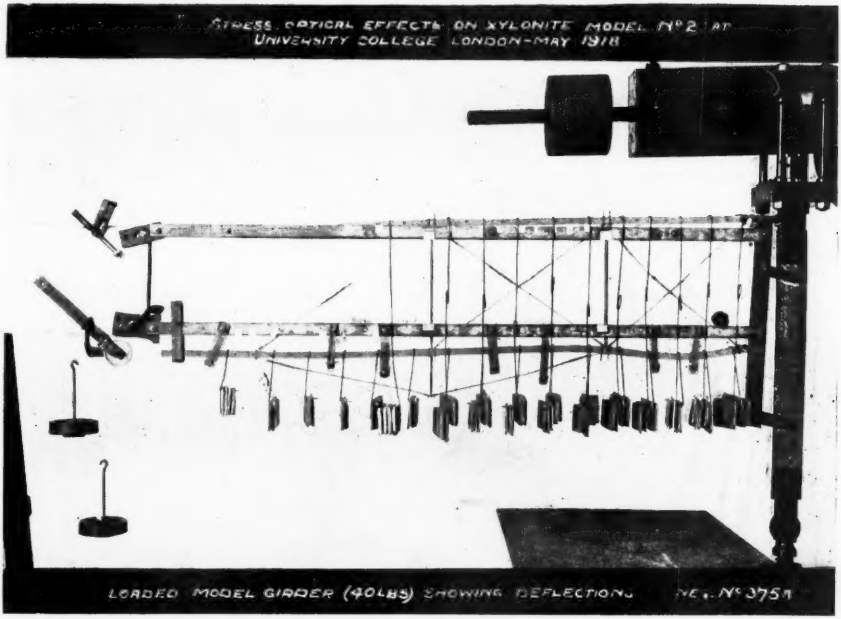

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2 AT
UNIVERSITY COLLEGE LONDON-MAY 1918
LOADED MODEL GIRDER (40LBS) SHOWING DEFLECTIONS
NEG. Nº 375A

FIG. 10.

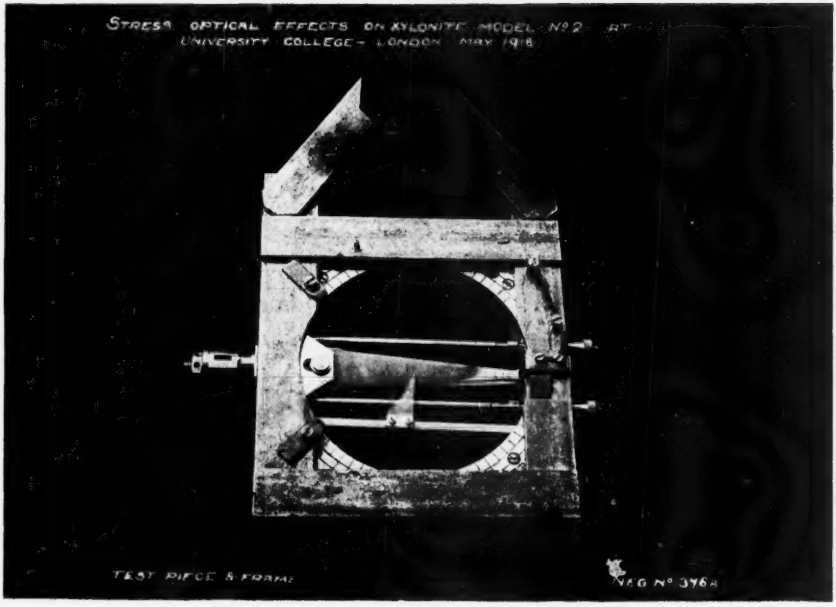

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2 AT
UNIVERSITY COLLEGE- LONDON MAY 1918
TEST PIECE & FRAME
NEG Nº 376A

FIG. 11.

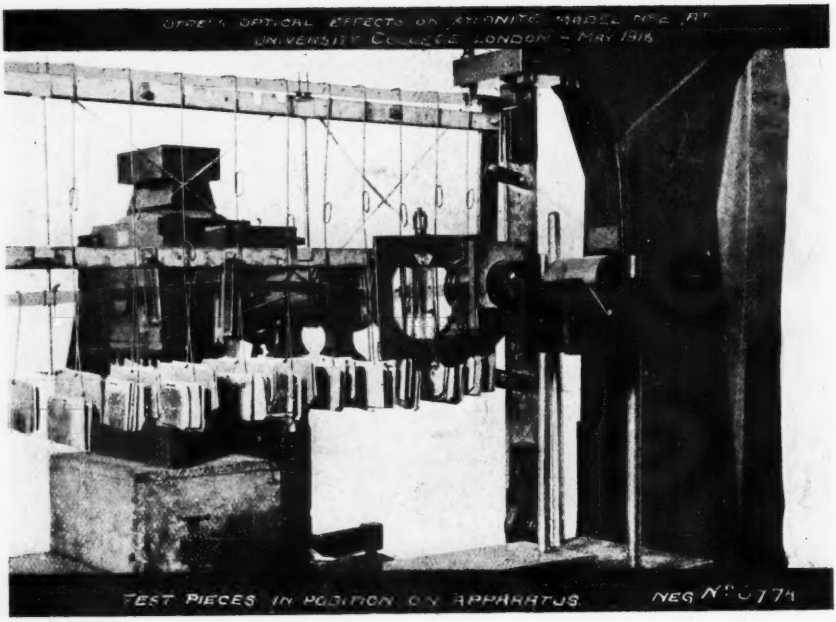

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 6 AT
UNIVERSITY COLLEGE LONDON - MAY 1918
TEST PIECES IN POSITION ON APPARATUS.
NEG Nº 3774

FIG. 12.

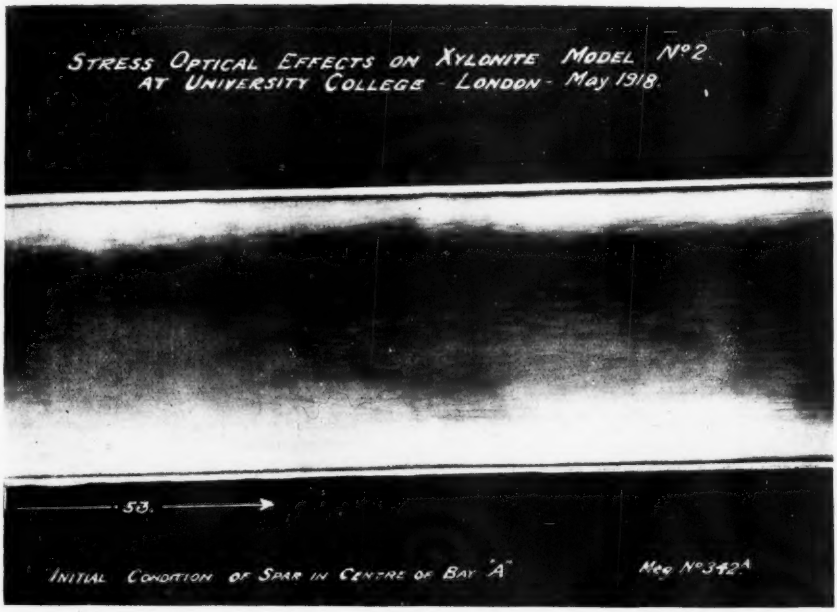

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 2
AT UNIVERSITY COLLEGE - LONDON - May 1918.
53.
INITIAL CONDITION OF SPAR IN CENTRE OF BAY "A"
Neg Nº 342A

FIG. 13.

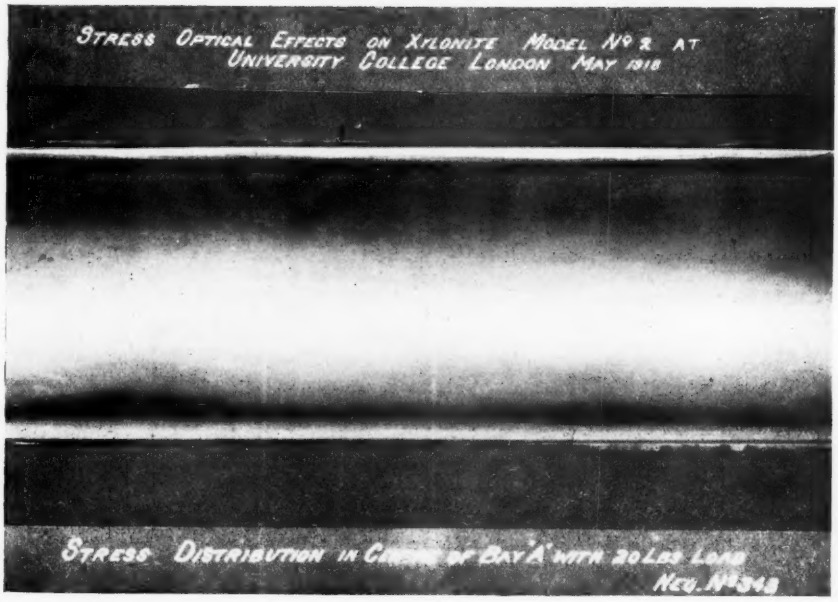

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 2 AT
UNIVERSITY COLLEGE LONDON MAY 1918
STRESS DISTRIBUTION IN CENTRE OF BAY 'A' WITH 20 LBS LOAD
NEG. Nº 343

FIG. 14.

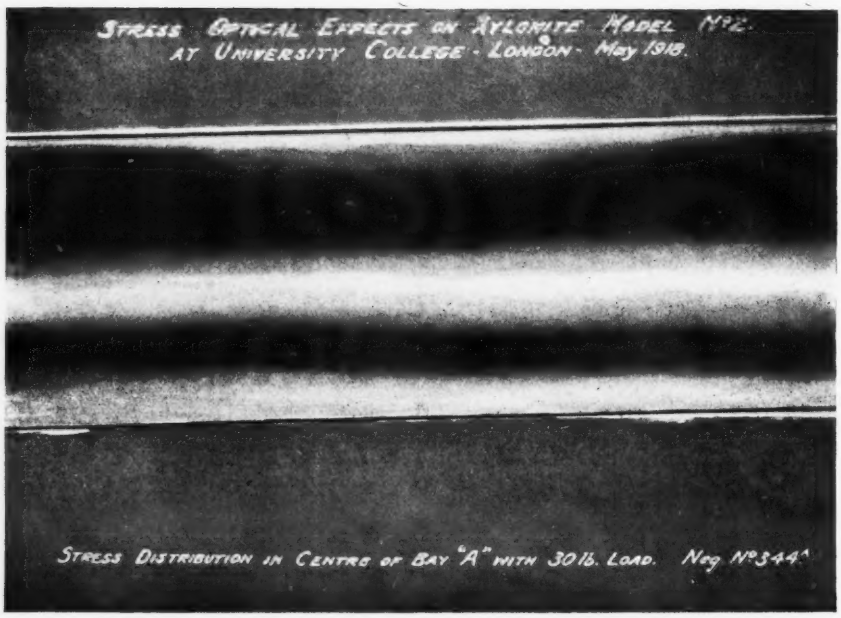

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2.
AT UNIVERSITY COLLEGE - LONDON - May 1918.
STRESS DISTRIBUTION IN CENTRE OF BAY "A" WITH 30lb. LOAD. Neg Nº344A

FIG. 15.

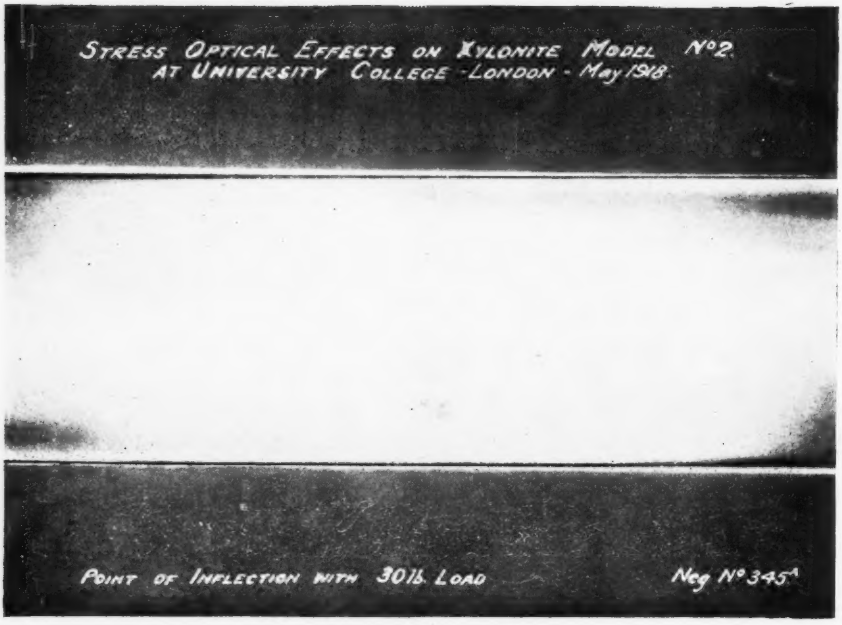

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2.
AT UNIVERSITY COLLEGE - LONDON - May 1918.
POINT OF INFLECTION WITH 30lb. LOAD
Neg Nº345A

FIG. 16.

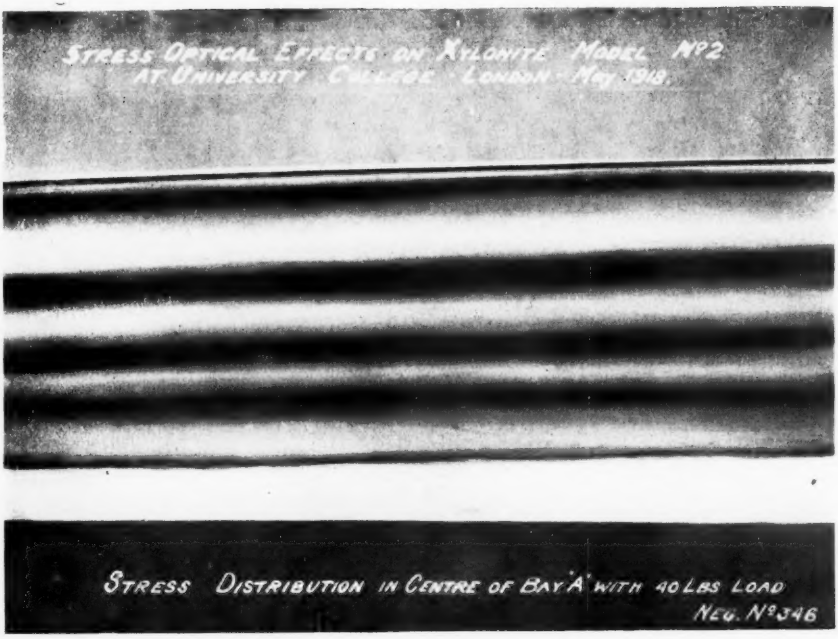

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2
AT UNIVERSITY COLLEGE - LONDON - May 1918.
STRESS DISTRIBUTION IN CENTRE OF BAY 'A' WITH 40 LBS LOAD
NEG. Nº346

FIG. 17.

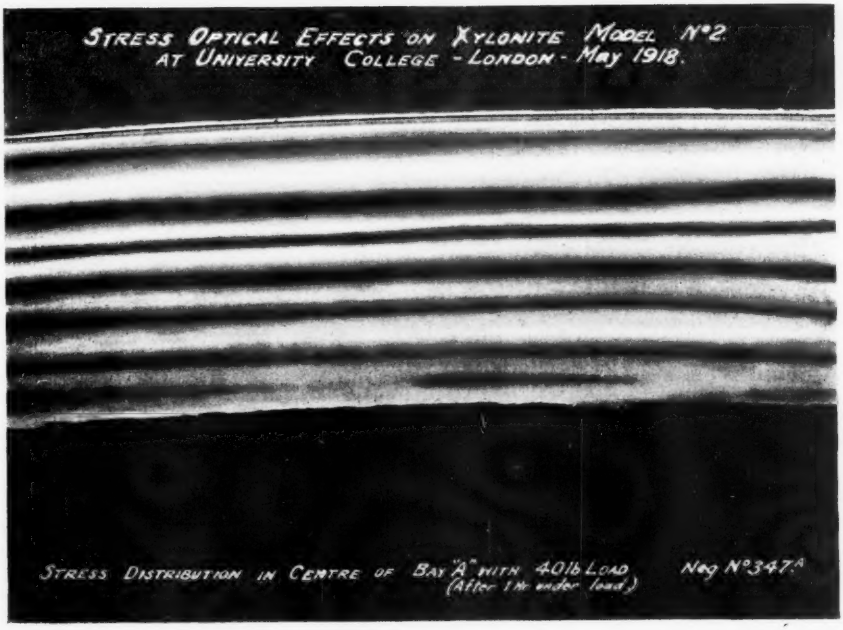

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2.
AT UNIVERSITY COLLEGE - LONDON - May 1918.
STRESS DISTRIBUTION IN CENTRE OF BAY 'A' WITH 40lb LOAD
(After 1 hr under load.)
Neg Nº347A

FIG. 18.

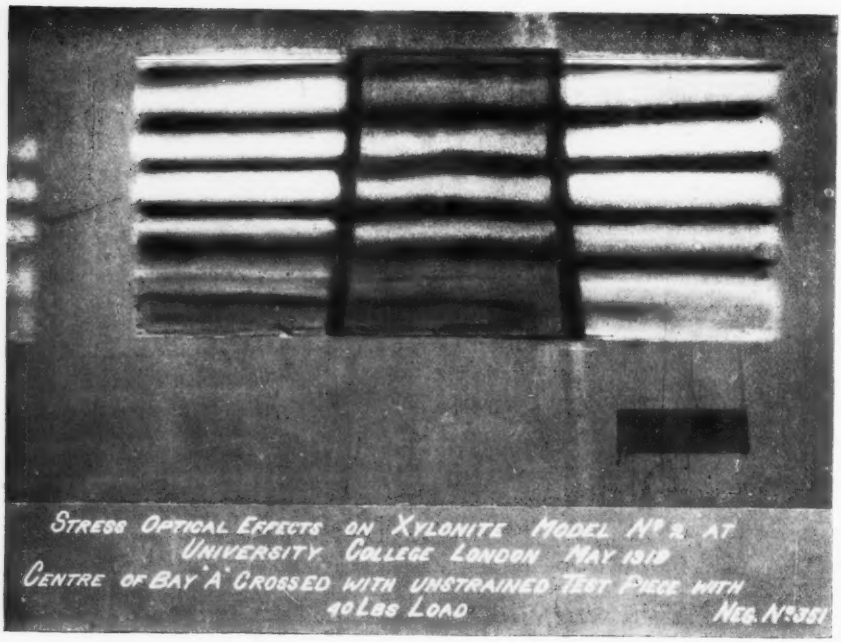

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 2 AT
UNIVERSITY COLLEGE LONDON MAY 1918
CENTRE OF BAY 'A' CROSSED WITH UNSTRAINED TEST PIECE WITH
40 Lbs LOAD
NEG. Nº 351

FIG. 20.

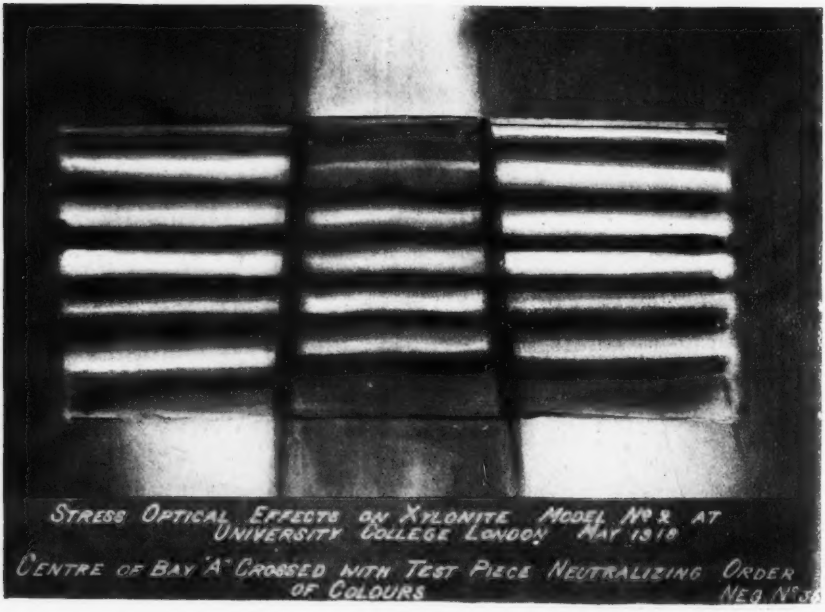

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 2 AT
UNIVERSITY COLLEGE LONDON MAY 1918
CENTRE OF BAY 'A' CROSSED WITH TEST PIECE NEUTRALIZING ORDER
OF COLOURS
NEG. Nº 35

FIG. 21.

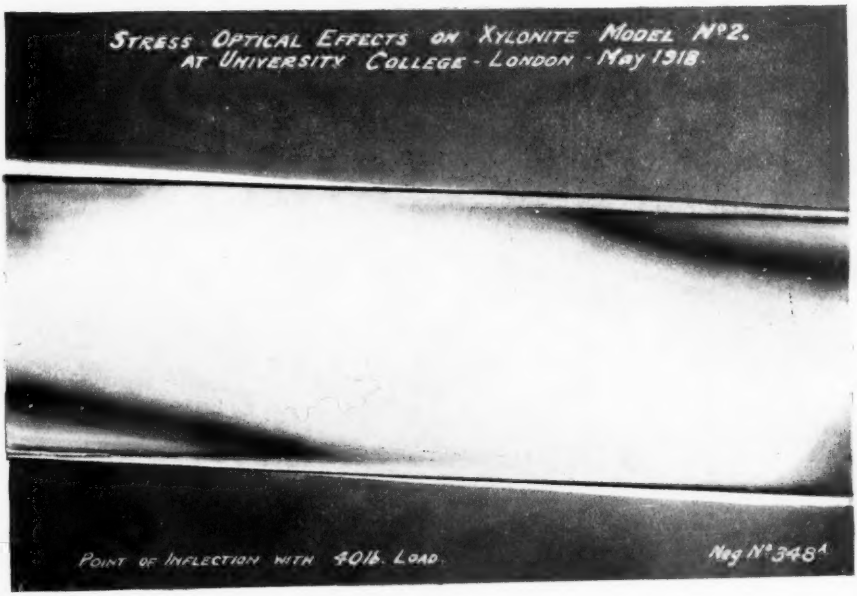

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2.
AT UNIVERSITY COLLEGE - LONDON - May 1918.
POINT OF INFLECTION WITH 40lb. LOAD.
Neg Nº 348A

FIG. 19.

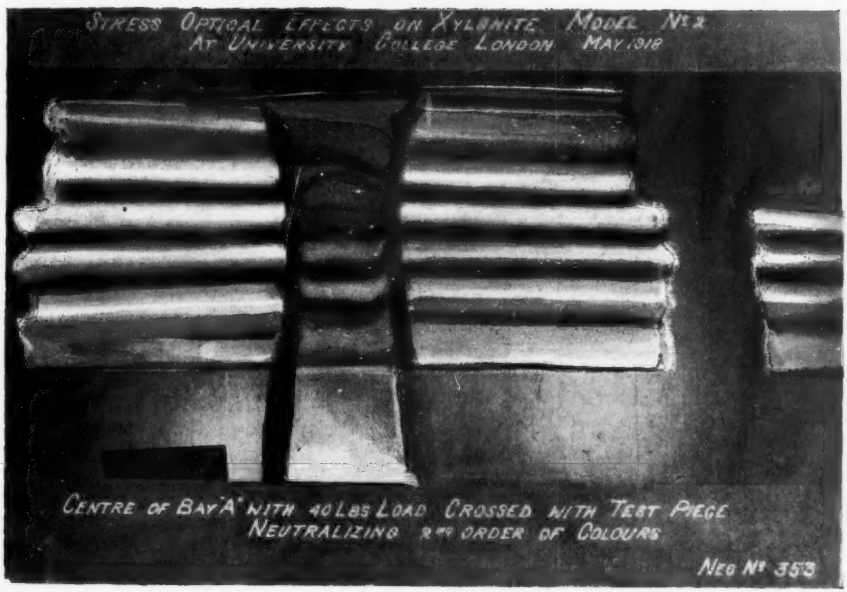

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº2
AT UNIVERSITY COLLEGE LONDON MAY 1918
CENTRE OF BAY 'A' WITH 40 LBS LOAD CROSSED WITH TEST PIECE
NEUTRALIZING 2ND ORDER OF COLOURS
NEG Nº 353

FIG. 22.

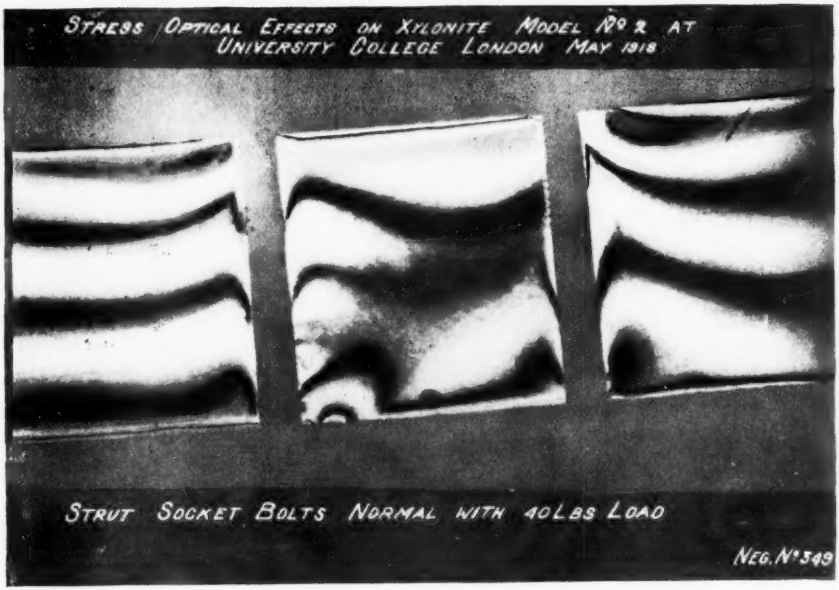

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 2 AT
UNIVERSITY COLLEGE LONDON MAY 1918
STRUT SOCKET BOLTS NORMAL WITH 40 LBS LOAD
NEG. Nº 349

FIG. 23.

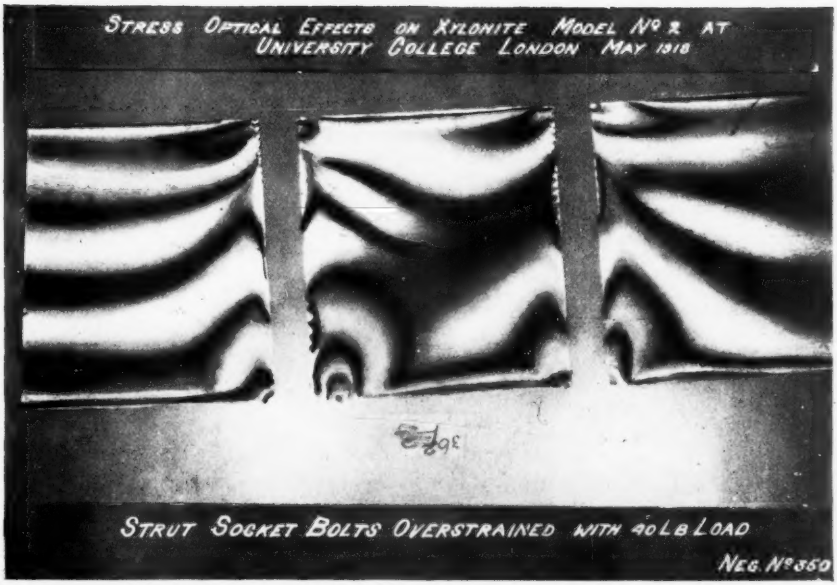

STRESS OPTICAL EFFECTS ON XYLONITE MODEL Nº 2 AT
UNIVERSITY COLLEGE LONDON MAY 1918
STRUT SOCKET BOLTS OVERSTRAINED WITH 40 LB LOAD
NEG. Nº 350

FIG. 24.

SECTION No. 3.

EXAMPLES OF OPTICAL OBSERVATIONS.

Fig. 13, Plate 342, shows the appearance of the image thrown on the screen when no external stress is applied. The pale orange colouring indicates a slight amount of stress which is either residual or is due to the weight of the girder itself. The two bright edges separated by dark stress bands from the main portion of the surface are caused by a surface effect in the xylonite itself, some physical change taking place in the worked edges of the material. Generally speaking the dark band represents the neutral axis slightly shifted upwards by the end pressure.

Fig. 14, Plate 343, shows the optical effect caused by a total load of 20 lbs. distributed as before. The neutral axis is shifted up in pretty much the same way as in Fig. 13, Plate 342, and the first order of colours partially appears as a broad band of pale orange in the lower edge, followed by a band of brick red.

Fig. 15, Plate 344, shows the effect of a 30 lbs. load distributed as before. The neutral axis remains approximately in the same position as the two preceding photographs and appears as a broad black band. Below, the first order of colours is completely shown, and the second order of colours also appears, showing a characteristic salmon pink as distinct from the brick red in the first order.

Fig. 16, Plate 345, shows the point of inflection with the 30 lb. distributed load. The point of inflection is symmetrically placed between the brick red wedges in the top right and bottom left corners.

Fig. 17, Plate 346, shows the optical effect of 40 lb. load distributed as before. The neutral axis retains the same position approximately, but the dark grey band which indicates it is much narrower than before. Three orders of colours appear below the neutral axis, while above the neutral axis the completed first order appears and most of the second order.

Fig 18, Plate 347, shows the optical effect under the same load after one hour. Marked creeping has taken place and a complete new order of colours has appeared below the neutral axis, namely, the fourth, and likewise above the neutral axis, namely, the third. Throughout this series it will be noted that the edge effect modifies the colour progression for a narrow strip at each edge.

Fig. 19, Plate 348, shows the point of inflection with 40 lb. load as before, by taking the mean position between the wedge of colour at top right and bottom left corners. The pale orange colour over the greater part of the surface indicates nearly uniform compressional stress caused by the end thrust. If there had been no end thrust the colour would have been a uniform dark grey tint as seen in the neutral axis in Fig. 13, Plate 342.

Figs. 20, 21 and 22, Plates 351-2-3, illustrate the use of a tapered test piece under known stresses. The test piece is described in Section 1.

Fig. 20, Plate 351, shows the test piece under no tension crossing the strained beam. It will be noticed that the neutral axis has not been displaced apart from a certain distortion caused by the test piece not being in the same plane as the beam.

Fig. 21, Plate 352, shows the test piece so strained as to neutralise the first order of red, the result being that the neutral axis has apparently shifted down the breadth of one colour band.

Fig. 22, Plate 353, shows the test piece adjusted so that the second order of red is neutralised, the result being that the neutral axis has apparently shifted down the breadth of two colour bands. In both cases the stress at the neutralised band of the test piece is equal to the stress in the model spar.

Fig. 23, Plate 349, shows the isoclinic lines and the isochromatic lines in the neighbourhood of two bolts piercing the beam and screwed up with moderate tightness.

Fig. 24, Plate 350, shows the result of overstraining the bolts (the loads in both cases being 40 lbs. distributed). The dark lines are no longer neutral axes, but a method can be worked out for evaluating the stresses in these two cases. For the present it is sufficient to remark that the condition of uniform stress gradient in the main portion of the beam is completely altered in the neighbourhood of the bolts, but is very nearly restored at a distance equal to the depth of the beam.

SECTION No. 4.

Fig. 25, Plate 627, gives dimensions of the model.

Fig. 26, Plate 605, shows the deflection curves for the top spar calculated and observed for total loads of 10, 20, and 30 lbs.

Fig. 27, Plate 606, shows the deflections for loads of 35 and 40 lbs. It will be noted that the observed and calculated deflections in the first bay tally fairly closely, but in the second bay a discrepancy appears which becomes more and more marked, up to the load of 35 lbs., where there is complete disagreement between the calculated and observed values when the deflection is considered with relation to the straight line joining the nodes.

The calculated deflections for 40 lbs. total load cannot be shown, as the calculated value reaches infinity for a total load slightly exceeding 36.6 lbs. This makes it clear that the elastic limit has been passed, and that the assumptions no longer represent the actual facts. Of the two curves shown for 40 lbs. load, the smaller represents the instantaneous deflections and the larger shows the deflections after one hour. On removing the load altogether, a certain amount of set remained, but after 24 hours' rest, the set had entirely disappeared. It has been suggested by Major Filon that the assumption of a perfectly elastic framework embedded in a plastic mass would account for the phenomena.

Fig. 28, Plate 607, shows the deflections of the nodes of the top spar. Straight lines are drawn from the origin at the point of support to the first node. Looking at the centre line of the second strut, it will be noted that the second node is above the straight line for loads 10, 20, and 30 lbs., is accurately on the straight line for 35 lbs., and is below it for 40 lbs. Looking at the centre line of the third strut the third node is on the straight line very nearly for 10, 20, and 30 lbs., but for 35 lbs. is well below, and for 40 lbs. is still further below the straight line. One of the assumptions on which is based the differential equation of C.I.M.9 is that the nodes are in a straight line. There is a further tacit assumption that this straight line is horizontal. It is probable that the displacement shown in Fig. 28, Plate 607, rises almost entirely from the shearing distortion of the girder as a whole.

If the nodes lay accurately on a straight line through the origin it is probable that the error in the differential equation would be of a small order, but the appreciable departure from collinearity shown probably affects the accuracy of the results greatly, and may account for the discrepancy between observed and calculated values appearing in Plates 605 and 606, Figs. 26 and 27.

Fig. 29, Plate 608, shows in the inner bay of the top spar a comparison between the bending moments obtained from (*a*) optical observations, (*b*) calculations by the method of C.I.M.9, and (*c*) from direct observations of the curvature, by taking second differences of deflections for a total load of 20 lbs.

Fig. 30, Plate 609, shows a similar comparison for a total load of 30 lbs., and Fig. 31, Plate 610, shows a total load of 35 lbs. For the 20 lbs. load it will be noted that the optical curve rises above the calculated curve, and below the observed curve. For the 30 lbs. load the optical curve rises above both the calculated and observed curves, the latter being roughly equal. For the 35 lbs. load the optical curve gives the largest value, the calculated curve the next largest.

The observed curve is rather smaller than the calculated, whereas, in Fig. 29, Plate 608, the observed curve is markedly larger than the calculated curve. Taking the three figures together it will be seen that the agreement between the three methods is distinctly rough, but from independent checks the accuracy of the optical method is probably much higher than the others.

Fig. 32, Plate 611, shows on a much larger scale the variation in the position of the point of inflection given by the last three plates. It can be shown easily that with no end thrust the calculated position of the point of inflection remains

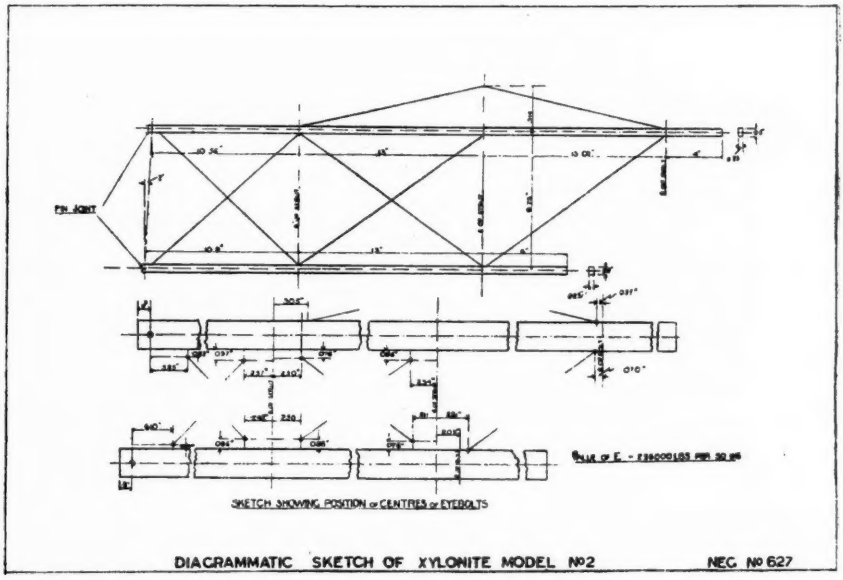


FIG. 25.

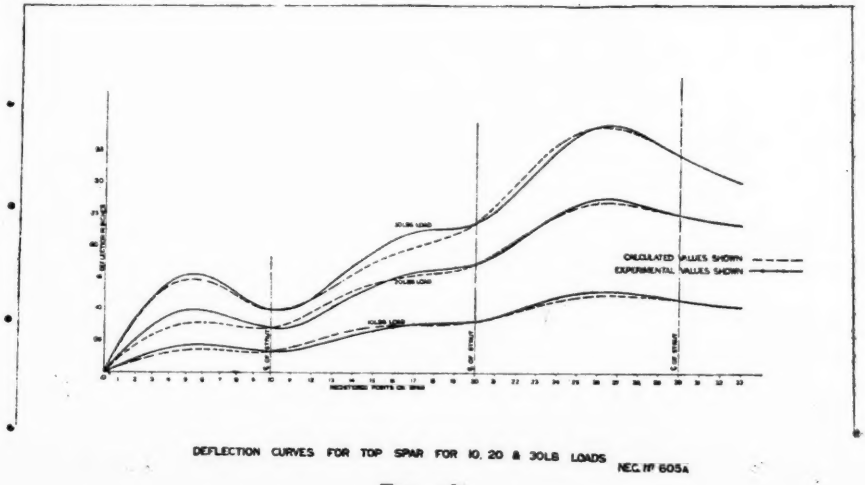


FIG. 26.

constant for any loading whatever, within the elastic limits, to a close approximation.

Plotting distance of the point of inflection from the centre of the bay against the load, a vertical straight line is obtained for no end thrust, and by calculating the position by the generalised equation of three moments a curve is obtained as shown in Fig. 32, Plate 611. This may be compared with the curves obtained by the optical method, and by direct observation of curvature. The discrepancies are too heavy to be accounted for by experimental error, and require further investigation.

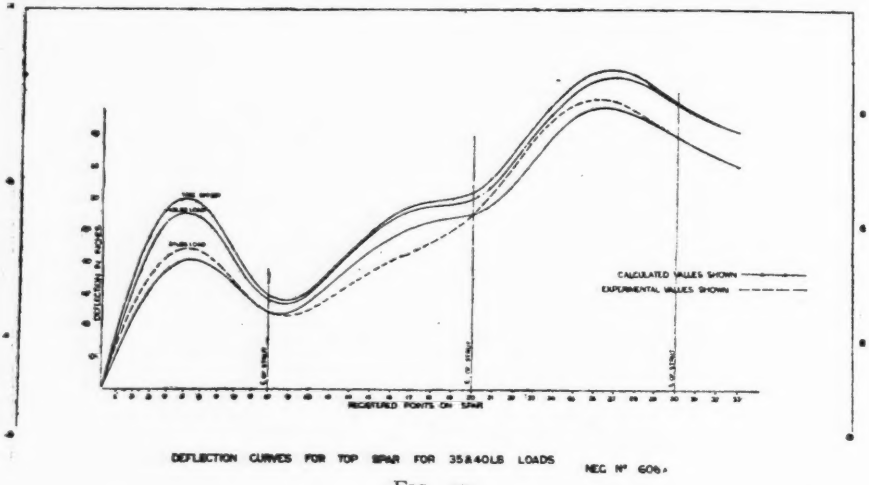

CALCULATED VALUES SHOWN
EXPERIMENTAL VALUES SHOWN
DEFLECTION IN INCHES
RECKONED POINTS OF SPAR
DEFLECTION CURVES FOR TOP SPAR FOR 35&40LB LOADS
NEG N° 606.

FIG. 27.

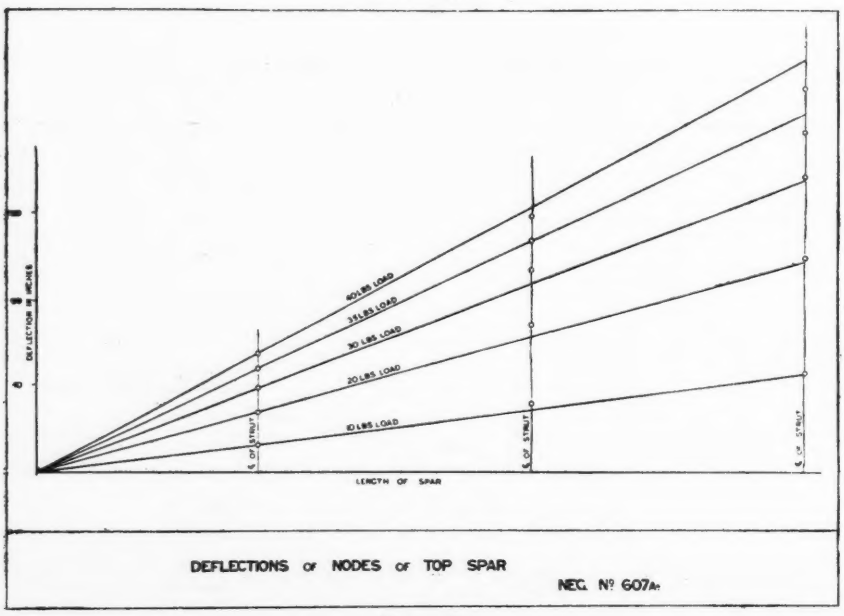
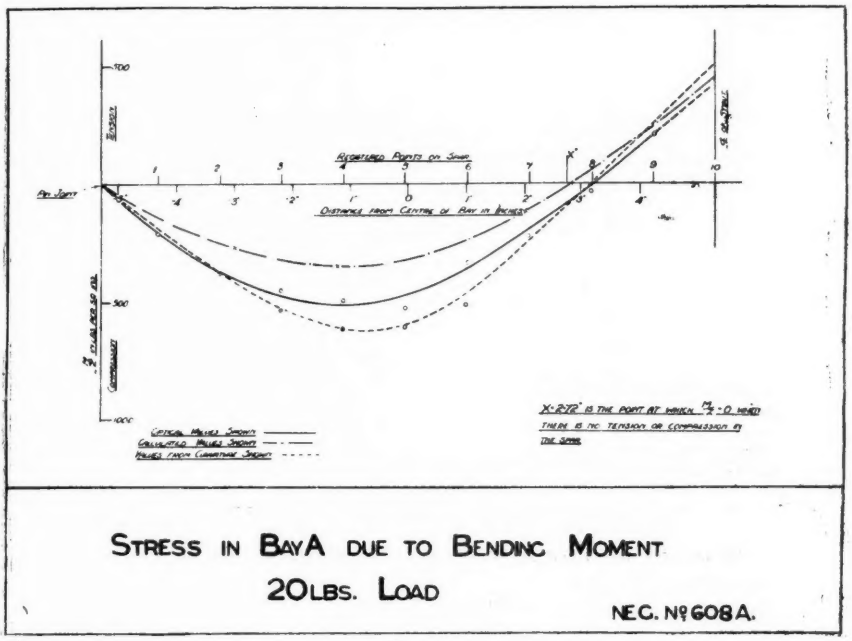
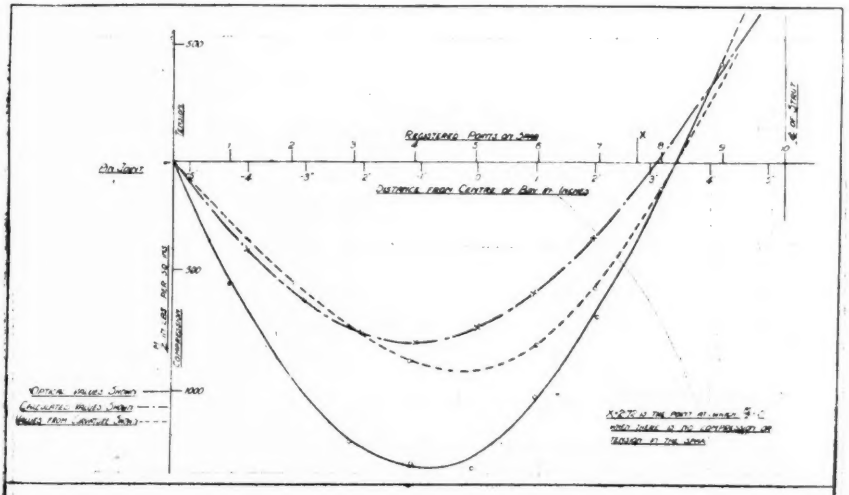


FIG. 28.


Recorded Points on Spar.
Distance from Centre of Bay in Inches
Critical Values Shown
Calculated Values Shown
Values from Curvature Shown
X=2.72" is the point at which f/c = 0. Here there is no tension or compression in the spar.

STRESS IN BAY A DUE TO BENDING MOMENT
20 LBS. LOAD
NEC. Nº 608A.

FIG. 29.


Recorded Points on Spar.
Distance from Centre of Bay in Inches
Critical Values Shown
Calculated Values Shown
Values from Curvature Shown
X=2.72 is the point at which f/c = 0. Here there is no tension or compression in the spar.

STRESS IN BAY "A" DUE TO BENDING MOMENT
30 LBS LOAD
NEC Nº 609A

FIG. 30.

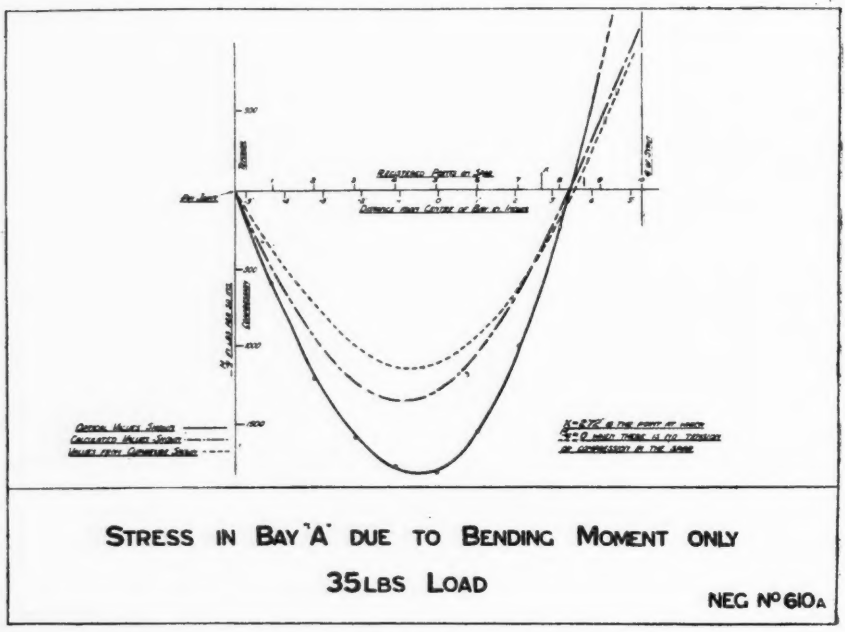

STRESS IN BAY 'A' DUE TO BENDING MOMENT ONLY
35 LBS LOAD
NEG. Nº 610A

FIG. 31.

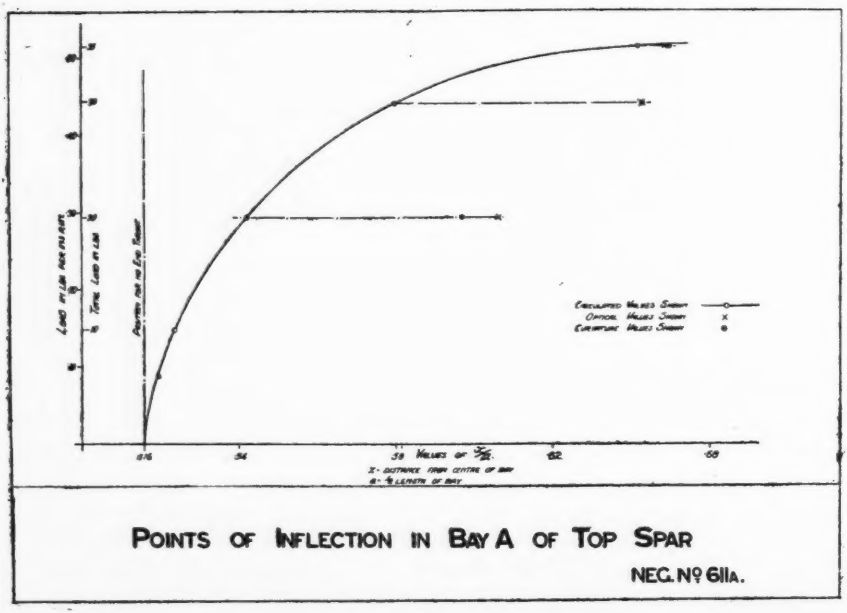

POINTS OF INFLECTION IN BAY A OF TOP SPAR
NEG. Nº 611A.

FIG. 32.

GENERAL REMARKS.

On looking back on the series of experiments, it is now possible to see that in some respects they were badly laid out. The illustration, Plate 375, of Loaded Model, and the Curves of Deflection, Plate 605, 606, show that the inner bay of the upper spar was far more severely strained and stressed than any other. One of the results was that discrepancies in the inner bay were of the same order as the total deflection in the second bay, and it is therefore not surprising that the heavy percentage difference between observed and calculated results in the first bay should be transmitted to the second bay in the form of discrepancies of the same order as the total deflection in the second bay.

For a reasonable comparison throughout the length of the spar all the bays ought to be strained in something like the same proportions. It is considered, therefore, that the comparison of deflections, etc., in the first bay only is likely to lead to valid results. Another point which was noticed after the experiment had been carried out was that the sockets taking the struts formed joints of considerable rigidity, so much so, that the heel of one of the sockets broke off under the excessive strain of a maximum load, thus indicating a very serious bending moment, which, however, had been ignored in the assumptions on which the calculations were based. The departure from collinearity of the nodes shown on Plate No. 607 has already been referred to. To what extent this discrepancy was caused by the unsuitability of the assumption of pin joints and to what extent they would occur were the pin joints made perfectly flexible and frictionless is a very important question. Probably the best way of repeating such an experiment would be to make two models, one in which the assumptions of frictionless and collinear pin joints were satisfied as nearly as is possible in the laboratory, the other containing the same departures from the assumptions as might occur in actual practice.

With regard to irregular stresses (Plates 349 and 350) caused by the tightening up of bolts, it is worth remarking that these stresses cannot be assumed to lie in parallel surfaces cutting the face of the spar at right angles. It would be necessary first to ascertain in what plane the stresses did lie before proceeding to find their value by an application of the methods used in the simpler case.

In measuring stresses of an irregular nature, particularly in the fittings not bounded by parallel plane faces, a rich field of research opens itself.

In conclusion, the method discussed in this paper should be regarded from two points of view. In the first place as a method already, within limits, in full working order and immediately available as an instrument for obtaining numerical values in particular engineering applications, and as such of immediate commercial value.

In the second place, it is to be regarded as a method for whose further and fuller development research should be encouraged and subsidised.

NOTE BY MAJOR FILON.

ON THE PRINCIPLE OF DYNAMICAL SIMILARITY APPLIED TO DEFORMABLE ELASTIC STRUCTURES.

(1) General Case of Structure of Finite Thickness.

Consider any deformable structure subjected to strain. Let a mechanical model of this structure be made accurately to scale, but of different material. We will investigate the relations which have to be satisfied by the elastic constants and the stresses applied if the deformations of the original system and of the model

are to be geometrically similar. Let k be the ratio of similarity of the model and the original, so that if l be any length in the original, kl is the corresponding length in the model.

If x, y, z are the co-ordinates of any point of the original (kx, ky, kz) are the co-ordinates of the corresponding point of the model.

If (u, v, w) are the displacements at (x, y, z), (ku, kv, kw) are the displacements at (kx, ky, kz).

The *strains*

$$S_x = \frac{du}{dx},\ S_y = \frac{dv}{dy},\ S_z = \frac{dw}{dz}.$$

$$\sigma_{yz} = \frac{dv}{dz} + \frac{dw}{dy},\ \sigma_{zx} = \frac{dw}{dx} + \frac{du}{dz},\ \sigma_{xy} = \frac{du}{dy} + \frac{dv}{dx}.$$

are identical in the model and original.

The *stresses* are given by

$$xx = \lambda\left(\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}\right) + 2\mu\frac{du}{dx}$$

and two similar equations

$$yz = \mu\left(\frac{dv}{dz} + \frac{dw}{dy}\right)$$

and two similar equations being the elastic constants of Lame.

Thus, in general, for dynamical similarity, all the elastic constants have to be altered in the same ratio q, and the applied stresses must be altered also in the ratio q.

(2) Framework of Thin Rods.

In the case of *thin* rods forming part of a plane framework under stress in its own plane, we have, if T be the total tension and M the bending moment at any point of a rod and T^1, M^1 the corresponding quantities in the model,

$$T = E\Delta s$$
$$T^1 = E^1\Delta^1 s^1$$

when s, s^1 are the longitudinal strains of the rod in the full size and model respectively.

E, E^1 are the Young's moduli, $\triangle$, $\triangle^1$ the cross sections of the rods. Now $s = s^1$ by geometrical similarity.

Hence

$$T : T^1 = E\triangle : E^1\triangle^1 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Further

$$M = \frac{EI}{R}$$

where I is the moment of inertia of the cross section of the rod about the neutral axis and R is the radius of curvature of the rod.

Similarly

$$M^1 = \frac{E^1 I^1}{R^1}$$

where clearly $R^1 = kR$ by geometrical similarity. Also let p be the ratio of *forces* (*not* stresses) in the model and full size. Then $M^1 : M = pk : l$.

$$\frac{E^1 I^1}{R^1} \frac{R}{EI} = pk.$$

$$\frac{R^1 I^1}{EI} = p.k.^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

But from (1) since $T^1 = pT$

$$\frac{E^1 \Delta^1}{E\Delta} = p \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From (2) and (3) by division

$$\frac{I^1/\Delta^1}{I/\Delta} = k^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Let K be the swing radius of the cross section of any rod in the full size and k in the model.

Then $I = K^2\Delta$
$I^1 = K^{12}\Delta^1$

(4) gives $\frac{K^{12}}{K^2} = k^2$

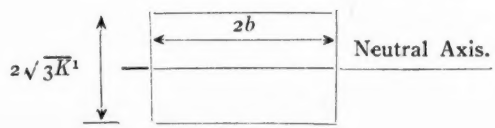
$$\text{or } K^1 = kK \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

That is, although the cross sections need not be geometrically similar (the rods being *thin*) the radii of gyrations of the cross sections *must* be in the ratio of *geometrical* similarity k.

This condition being once satisfied equation (3) shows that the moduli $E\Delta$, $E^1\Delta^1$, for the rod as a whole must be in the ratio of dynamical similarity p, *i.e.*, in the ratio of the applied forces.

Now k will usually have to be fixed beforehand; k being known, the radius of gyration K in the model is fixed.

The materials of the model are also usually not at our choice. Thus E^1 is fixed. But Δ^1 can be varied within large limits, and this without altering k. An easy example of this is when the bars of the model are rectangular in section.



The height of the cross section $= \sqrt{12}K^{12}$ and is therefore fixed. But the breadth $2b$ is at our disposal and can be varied so that Δ^1 satisfies equation (5).

An important particular case occurs when certain rods or ties of the full size are practically unyielding or inextensible, at any rate in comparison with the others. In this case $E=\infty$ and $E^1=\infty$.

All that is necessary then is to make the corresponding bars of the model likewise unyielding or inextensible in comparison. Provided this is done, we need only trouble to satisfy the conditions for the " yielding " or soft parts of the model and full size.

If the model and full size are made up of *two* kinds of material only—a " yielding " and an " unyielding," it will usually be convenient to satisfy equation (3) by adjusting p, the ratio of dynamical similarity, that is, by applying suitable loads to the model instead of altering the cross sections to the right ratio.

(3) Safety Conditions for the Model.

The question of breaking stress on the model is one of fundamental importance. For we have to be careful that the stresses imposed in conserving similarity shall not be so great as to cause the model to collapse.

We have, y and y^1 being the distances from the neutral axes of the outermost fibres in full size and model respectively, the greatest stresses, as follows :—

$$Es + \frac{Ey}{R} \text{ (full size)}$$

$$E^1s^1 + \frac{E^1y^1}{R} \text{ (model)}$$

(numerically positive values being taken for each quantity).

Now $s^1=s$, $R^1=kR$; but $y^1=ky$ in general.

As, however, $K^1=kK$, in the case of *rectangular* bars $y^1=ky$ accurately, and it is not unreasonable to suppose that y^1 will generally be of the order ky. (Note, for *similar* sections $y^1=ky$ also.)

Thus, we may take the case of rectangular bars as fairly typical. We have then $Y/R=Y^1/R^1$ and greatest stress in model; greatest stress in full size $=E^1:E$.

That is, greatest strain in model = greatest strain in full size. Hence, the greatest strain to which the material of the full size is subjected in the case considered must not break down the material of the model.

If the model is made of much more yielding material than the full size, the material of the model will as a rule stand a much greater strain than that which would break material of the full sized member.

Xylonite is a much more yielding material than wood. So that if the full size spar is of wood and the model of xylonite, the conclusions of the last paragraph hold good. Loads on the xylonite model will still usually be well within the safety limit, even when the corresponding loads on the full size wooden member exceed the safety limit—a point of great value in investigating dangerous stresses.

PROCEEDINGS.

The second meeting of the session was held in the Hall of the Royal Society of Arts, London, on Wednesday, November 20th, Major L. N. G. Filon presiding.

A recommendation by the Council that Rule 24 be altered to read as follows was approved:—"The Council shall consist of 20 voters of the Society, of whom one half shall be Fellows or Associate Fellows of the Society." This increases the number of the Council from 16 to 20 members.

The CHAIRMAN said Major Low, who would deliver a lecture that evening, was a veteran member of the Society, and he was one of the pre-war pioneers in aviation and took his pilot's certificate as far back as 1910. He was also one of the first professional engineers to take up aviation, and to insist on the necessity, which was now universally admitted, of applying scientific methods to the problem of flying. He had contributed a number of very valuable papers, embodying that point of view, to the proceedings of that Society before the war.

Major A. R. LOW, R.A.F., then delivered his lecture on "Stress Optical Experiments." (See page 341.)

In conclusion the lecturer acknowledged the assistance of Mr. Chakko, research student at University College, who checked the optical method. Over 287 observations were made. In simple cases where there was no question about stresses set up by simple bending moment the mean probable error was something like 3 or 4 per cent., whereas they had been looking at discrepancies of 30, 40 and even 200 per cent. between the calculations and the optical check. He also thanked the Controller of the Technical Department for his generous policy in allowing him to present these results in public.

Mr. HOWARD FLANDERS asked whether Major Low had any reason to think that if the pin joints were correct there would be a considerable similarity between the optical and the calculated methods?

Major G. I. TAYLOR asked whether the method described showed the actual tension or compression? He presumed that if the model were put inside a cube of water and the water were compressed it would not show any colours. In a stress of 15 lb. to the sq. in. it was under the atmospheric pressure, and it seemed probable that these colours did not come from compression but from shear. In any bent or stressed medium which was under tensions and compressions and shears the relationship between those different types of stress varied according to the physical properties of the elastic material. In the case of jelly or celluloid, which had a very large strength to resist compression, but a very small strength to resist torsion, he believed mathematicians would express that by saying that the Poisson's ratio was a half. The compressions would be different in many cases from what they were in the case of steel or wood, where the Poisson's ratio was not equal to a half, and where the strength of compression was of the same sort of order as the strength for shearing. The method might do in the case of marrow beams, but would it be satisfactory for things like bolt heads? The results were pretty from a qualitative point of view, but he would like to know how accurate they could be from a quantitative point of view.

Mr. T. W. K. CLARKE asked whether it was correct to speak of the colour effect as stress effect rather than strain effect. In the case of a stress, if there

were any slight flaw the maximum stress due to bending would be reduced, but the maximum strain would be increased, which, he thought, tended to show that it was a strain rather than a stress effect.

Mr. SUTTON PIPPARD said it was extremely serious for an error between calculated and observed stress to be of the order of 200 per cent. He thought the explanations given by Major Low were partly correct. The end fixing had a tremendous effect on the stresses. The great deflection in the inner bay introduced a special case which he believed had been completely dealt with by Messrs. Cowley and Levy of the National Physical Laboratory. He thought their paper would clear up quite a lot of the discrepancy. With regard to the creep, the discrepancy between the stress figures appeared to be greater on the higher loads. When the load on the model was 36 lbs. the error was greater than when it was only 10 or 20 lbs. Was the 10 or 20 lb. load carried for any length of time and did the creep start from the earlier loads? In that case it was possible that the correct figures were not obtained for the stress. On the lecturer's two figures there was a serious error after an hour's lapse of time when carrying the 30 lbs. Was it not, possibly, due to the previous load having been on a considerable length of time? Some five years ago he carried out some destructive tests on a full-sized machine, in order to compare the actual breaking stress with the calculated stress on the C.I.M.9 method—the method the lecturer had used for his calculations—and there was nothing like 200 per cent. inaccuracy between the calculated stress and the stress which actually occurred. (Major Low: The 200 per cent. was the discrepancy in the movement of the point of inflection. That went to reduce the discrepancy. The discrepancy in stress determination was 40%.) It was quite sufficient to need clearing up. In the experiments he referred to he thought the errors were under 10 per cent. in each case.

Mr. ALLARDYCE asked for information as to the skin effect on these models.

Miss HUDSON said, in regard to the position of the points of inflection, it seemed that both the calculations and the experiments showed that the inflections were very near the middle of the bay. If the measurements had been taken from the ends of the bay instead of near the middle the inflections would probably have been quite small.

Captain G. T. R. HILL said, considering the vast difference between the results of the optical stress and the calculated method figures, how would that affect the design of machines, more especially as regarded the spars and the wings?

Air Mechanic ANDREWS, R.A.F., said Major Low had drawn straight lines from the point of suspension to the first node. Did he also draw lines to the second or third points and see how the deflection appeared with respect to those lines?

Lieutenant-Colonel R. DE VILAMIL asked whether Major Low had any photographs of colour effects of simple shear?

Mr. TINSON asked, in the calculations on the spars, was the reduction assumed to agree at points where the ribs would come, or was the loading assumed to be distributed evenly right along the spar?

Colonel CAVE BROWN CAVE asked whether any particular precautions were taken in constructing the joints at the head of the struts to get the correct degree of rigidity? He understood the method of calculation was based on pin joints connecting the struts to the spars. The type of joint in the model was, presumably, not identical with that used in the actual machine. If the difference between the calculated results and the optical results depended on the nature of the attachment of the struts to the spars, it was necessary to investigate how far the construction in the model faithfully represented what existed in the aeroplane.

The whole system depended upon the question raised by Mr. Clarke as to whether the optical indication showed the result of stress or straining. If it were the latter it appeared most necessary to make sure the xylonite was free from initial strain before the loading was put on, and also that sufficient time was allowed to let it pick up its final condition of strain before taking readings and deducing the stress from them.

Professor E. G. COKER said Major Low stated that so far as his observations went they were correct within 5 per cent., which was sufficiently close to rely upon. The slides of these colour effects were impressive, but the actual photographs were much more so. A point that always arose in these discussions was that Poisson's ratio when using such things as celluloid would not be the same as when using other materials. If experiments were made with xylonite and steel or other elastic material and the calculations were made and substantial agreement obtained, it was reasonable to suppose that the proper value would be got in the cases where the stresses could not be calculated. The equation on which all elastic phenomena depended in the use of materials did not involve any constants. It had no E or N, no Yound's modulus and no Poisson's ratio. Therefore, provided the material were elastic and the stress and the optical law the material followed were known, one could not go far wrong. It had been asked whether the stresses at the bolt holes could be ascertained. That could be done, but the colour effect could not be entirely depended upon in those cases. The colour effects depended upon the difference of the principal stresses, and to analyse such a complicated picture as the one they had seen it would be necessary to get the directions of the principal stresses, and some means of separating them. Having got the stresses $P - Q$ and $P + Q$, and the directions, one could solve the problem. It had been done in the case Major Low mentioned, and had so far been accurate. In reference to the question about photographs showing shear, the pictures the lecturer had shown were pictures of different stresses. They were practically all shear pictures. If the gentleman who asked the question wanted pure shear pictures, they had a great number of these, which he would show him. He had made an experiment illustrating what would happen if the model were compressed in water. The loss of retardation which gave the optical effect was equal to its own constants, and if there were cubical compression there would be stresses in the two directions of equal value, and the optical effect could be measured with equal stresses at right angles. He imbedded the model between two celluloid plates thick enough to stand considerable pressure. With the cubical compression there was a colour effect due to the complicated stresses resulting from the bending of the plates. He came to the conclusion that the stresses in one direction gave no optical effect.

Mr. GUEST said he took it that the bolt holes were drilled through the celluloid representing the spar, and one could not derive the stresses at those corners from that experiment.

The CHAIRMAN said the method described in the lecture was not new, having been discovered by Brewster in 1816, but it had not been used much by the British engineer. Professor Coker took it up, and applied xylonite to the purpose, as it was difficult to use glass. It had only been since the adoption of xylonite that the method had given promise of solving a large number of engineering problems. The method had the advantage that the stress could be actually seen. It was pretty definitely established that the optical effect was due to stress and not to strain, because if semi-plastic material were completely distorted and afterwards allowed to get into a state of ease as regarded stress, although the strain was considerable, all the colour effect would disappear, so that if there were an effect of strain, as apart from stress, it was very little. In other engineering methods of examining stresses the deflection of the material was necessarily observed at surface points, and the stress at internal points was deduced by a theory which

in nearly every case involved some very doubtful approximations and in other cases failed entirely just when things began to get interesting—when the material approached the point of failure. It had been urged that the optical method results could not be transferred from xylonite to steel because the elastic constants were different. He thought Professor Coker meant that the equation he had mentioned was independent of the ratio of the elastic constants only in the case of plate strained in its own plane. That was precisely the case Major Low had been talking about, and, therefore, provided the elastic limit were not exceeded, the result should be the same in the xylonite and steel. The optical method was not necessarily confined to plates or rectangular bodies, and he saw no reason why it should not be applied to investigating the flexure of bars of other sections, but there was no general method available for that, and he thought the optical method must fail where the directions of principal stress—the axes of polarisation of the light—were continually changing, but that did not frequently happen in engineering applications. As regarded the discrepancies in the calculations and the optical experiments, the only suggestions he could put forward were that the nodes on the framework were not collinear, which might have considerable influence on the stresses, and that Major Low had sensibly overstrained his model, and the increased sag in the bar, which was both under flexures and under end-thrust, increased the bending moment due to the end-thrust.

Major LOW, in replying to the discussion, said his humble duty had been to bring together certain practical problems in aviation and assisting men and means for solving them. He had the help of Professor Coker's magnificently equipped laboratory and highly trained staff, and Major Filon had always been behind him in case he stumbled on knotty physical points. In reference to the questions about pin joints, the fact that the joints were rigid caused part of the discrepancy. He thought Mr. Pippard and his staff at the Air Ministry were amply competent to spot those discrepancies and allow for them, and that if the Air Ministry staff had carried out those experiments the discrepancies would largely have been accounted for. The assumptions he had made on his model resembled the assumptions nine out of ten designers made for full-sized machines. He accepted Major Filon's statement that the colour effect was a stress rather than a strain effect. They did not notice the extraordinary creep with the small loads, though some small creep might have been there. The 200 per cent. referred to by some speakers was merely the change of position of the points of inflection. The shifting of the point of inflection was always in a sense to reduce the maximum stress on the spar, which was all to the good. As a check on the whole elastic theory as applied to beams, he thought it was an important point, and if Professor Coker's laboratory was available for Air Ministry research, he hoped Mr. Pippard and Miss Hudson would pay particular attention to the point of inflection. The effect of the discrepancies on the safety of the design he had not considered. The object of the paper was to advertise an independent check on the methods of calculation. In reply to Air Mechanic Andrews, he drew the straight line from the first node because it exaggerated the behaviour of the other nodes. There was the result for Mr. Pippard to worry at. The load was uniform throughout, distributed over one-fifth of each span. The loading was the same as if there had been no rib at the joints, but a rib at every fifth part of the bay, starting one-tenth from each end joint. With regard to the important question raised by Colonel Cave-Brown-Cave, as to whether there was dynamical similarity in the rigidity of the joints, the Chairman had contributed a note on "Dynamical Similarity," and he thought when it appeared in the JOURNAL it would meet thoroughly Colonel Cave-Brown-Cave's question. The Chairman had already pointed out that where the stresses were not parallel to the faces of the strained member there were certain complications. He could only ask for research along those lines until this method was carried as far as possible. Certain large bridges in France had recently been designed on the results of stress optical methods, carried out on the glass frames,

and the difficulties the Chairman adverted to in manufacturing glass were got over. The glass was cut in slips, with more or less plane faces. The slips were glued together, and the glued joint was held by the French engineers not to affect the validity of the optical method. He hoped the Air Ministry would take up the method as an immediately practical method, and that the well-equipped centre at University College would be encouraged and subsidised. He wished to express his thanks to Mr. Widdicombe for his help, and to Cadet McGowan and Air Mechanic Warren who had plotted curves. Mr. Chakko had carried out 285 measurements to verify the accuracy of the method, and had assisted in the optical experiments.

Mr. Wood and Captain Gordon Jones were responsible for the photographic work, the coloured photographs by the Lumière process being particularly successful. It was impossible to over-estimate the value of having in collaboration at University College Major L. N. G. Filon, a recognised authority on elasticity and optics, and Prof. E. G. Coker, a recognised authority on the application of stress optical methods to engineering problems.

ABSTRACTS.

Use of Carbide for Aerial Motors.

Experiments are being conducted at Messrs. Nielson and Winther's aeroplane factory, Copenhagen, with a motor fuel made from carbide. A Danish engineer, Herr Carsen, of the Danish State Railways, originated the idea and the experiments will probably be concluded in about fourteen days. If the results correspond to expectations, a factory will be erected at Amager for the production of aeroplane carbide. The costs of production are at present high. ("Göteborgs Handels-Tidning," Sept. 11, 1918.)

Fokker D.VII. Single-Seater Biplane Scout.

This machine has appeared recently on the French front and is among the best of enemy scouts. The span of the upper wings is 29ft. 3½ins., and that of the lower 23ft., whilst the overall length of the fuselage is about 23ft. The machine has a lifting surface of 233 sq. ft. and a total weight, loaded, of 2,110 lbs. The motor is a 160 h.p. Mercedes, modified.

The chord of the upper wings is 5ft. 3ins., and of the lower 3ft. 11¼ins., and the wing section is very thick (9ins. maximum). There is a positive stagger of 26.7° between the planes. The steel tube compression ribs usual in German construction are absent in this machine, but the framework of the balanced ailerons is of steel. Each of the wing spars is composed of two strips of red deal, connected by vertical surfaces of three-ply. Each of them is also all in one length, the lower spars passing right through the fuselage and being connected to cross-members of the base of the latter by collars. The lower wing spars are of very light construction. There are no bracing wires between the two planes. The wing struts on each side consist of three stream-lined steel tubes, one of which is a diagonal welded to the base of the front and top of the rear strut. Between the fuselage and the upper wing are four very divergent steel struts on each side. Two struts connect the rear spar to the base of the fuselage near the rear legs of the chassis, two join the front spar to the top longerons, and the other four, welded in pairs, join that spar to the fore legs of the chassis and to the foremost of the motor support tubes.

All members of the tail have a steel tube framework. The tailplane is triangular, and the elevators and rudder are balanced.

The fuselage has a metal framework autogenously welded and is covered with fabric. There is a light alloy sheet cowling around the engine. At the nose is a honeycomb radiator resembling that of an automobile in form. A shutter on a vertical axis, and actuated from the cockpit, is fitted on the interior side. Two Spandau mitrailleuses fixed to the top of the fuselage may fire separately or together through the propeller.

The under-carriage consists of four stream-lined steel tubes welded at the base to a special form of sheath carrying the axle of the chassis. Elasticity is secured by springs fitted between axle and sheath. This sheath is enclosed by a plane of plywood which is large enough to contribute to the lifting surface.

The speed on the ground is about 120 m.p.h., and at 16,000ft. it is 96 m.p.h. The machine climbs 15,000ft. in half an hour. ("L'Aerophile," September, 1918.)

Alignment Chart for Obtaining Heights.

By means of a d'Ocagne alignment chart the solution of Laplace's formula

for the height above datum line in terms of the pressure and temperature may be easily accomplished.

Laplace's equation is

$$z = 2.21 \times 10^2 \, T \log \frac{p_0}{{}_{10}p}$$

This may be written in the form

$$\log z = \log (2.21 \times 10^2) + \log T - \log \left(\frac{1}{\log R} \right)$$

where

$$R = p_0/p.$$

Use is then made of the fact that if three parallel lines be drawn along which three different variables are plotted, say, U, V and W, then by a proper adjustment of the origins of each of these, any straight line cutting the parallels does so at points satisfying the relation

$$U = U_0 + AV + BW$$

where A and B are constants depending on the distance apart of the lines. This may be made identical with the modified equation whose solution is required by adjusting the constants and setting

$$U = \log z, \; V = \log T, \; W = \log \left(\frac{1}{\log R} \right)$$

These three quantities are thus plotted along the parallel lines and a straight-edge, joining corresponding values of p and T, cuts the third line in the required value of z. (A. H. Stuart, "Aerial Age," Sept. 9, 1918.)

Construction of Aeroplanes.

The Norwegian Aeroplane Factory, which is the name of a newly formed company, has secured land for the construction of the necessary buildings near Tönsberg.

According to estimates about 40 machines will be built annually. Three different types will be built, of which two are completed, one of 165 h.p. to carry 4 persons, the other 500 to 600 h.p. to carry 8 persons. A smaller racing type will also be constructed with a speed of 25-30 miles an hour (Norwegian mileage). The types are exclusively hydroplanes. Trial flights will be made with sulphite spirit and carbide. ("Politiken," Oct. 12.)

Transatlantic Flight by Aeroplane.

Attention is confined to the problem of the possible delivery of American and Canadian built bombing planes by air route during the present war. Three routes are considered, viz. :—

(1) The All-British, from St. John's, Newfoundland, to Valencia Island, Ireland, involving a non-stop run over the Atlantic of 1,923 miles.

(2) The Northern route from St. John's to Christian Sound, Greenland (940 miles), then to Reykjavik, Iceland (730 miles), and on to Lewis Island in the Outer Hebrides (635 miles); making a total of approximately 2,300 miles.

(3) The Southern route from St. John's to the Azores (1,200 miles), St. Michael (312 miles), Lisbon (850), and then to Plymouth (700 miles), with a total of over 3,000 miles.

Political considerations are against the northern route, and the length of journey and the surface conditions of the Azores against the southern, but the all-

British route contains a very long non-stop run. Meteorological conditions favour the all-British route for flight from West to East, since by a suitable choice of course one half of the prevailing winds blows from a westerly quarter at 21 m.p.h. for the first 1,000 miles, while three-quarters of the winds blow from the same quarter at 28 m.p.h. for the remainder of the journey. The northern and southern routes would be only on the very fringes of this cyclonic belt. A favourable wind of 20 miles per hour would add 480 miles to a day's flight.

The directional problem, type of aeroplane required, and the method of propulsion are treated at some length, and an estimate for the distance an aeroplane can travel on its own fuel is given as approximately 1,200 miles, using present-day figures.

Mention is made of constructing aerodromic ships protected by patrol boats and scout boats. The landing platform, it is stated, should be at least 600 by 150ft. (" Aviation," Sept. 15, 1918.)

Italian War Aviation.

This article describes the present condition of military aviation in Italy:—

As to *fighting* aeroplanes, we now turn out two splendid types, the A1 (so-called " Balilla "), a machine developed from the S.V.A. of the Ansaldo Factory, and the " Pe-Gamma," from the original plans of the Pomilio Works (recently taken over by the Ansaldo Factory).

We thave two types of *scouting* machines of high value—the SIA 8-B (developed from the former 7-B type), made by the SIA Factory, which is a branch of the FIAT, and the P.F. of the Pomilio Factory.

For *day bombing* two Italian machines are ready to-day which have already undergone severe tests. One is the S.V.A., built by the Ansaldo Factory, which can be used for fighting and scouting; the other is the SIA 9-B, equipped with a FIAT engine of 700 h.p., which, owing to its speed and great power, can be flown over long distances and used in broad daylight bombing.

For *night bombing* there are the biplane and triplane Caproni. The larger model of Caproni biplane (CA-5), equipped in Italy with three FIAT motors of 300 h.p. each, is without doubt superior to all similar types, so much so that our Allies have largely adopted it. It is also known to-day that the first Caproni built in the United States, and equipped with American Liberty motors, has gone through its tests with the greatest success; and the Federal authorities have since placed with American firms large orders of Caproni-Liberty aeroplanes.

The FIAT Factory stands first as one of our largest manufacturers of aviation motors, with her two well-known engines, the A-12 and the A-14. The A-12 develops 300 h.p., and the A-14 700 h.p., this being the most powerful motor used at the front for aviation by any of the Allies. The FIAT has a remarkably large output of these engines. Our Aeronautical Department, which buys all this production, after meeting all our own requirements, supplies the Allies with an important number of these motors daily. Besides this, the FIAT has now ready a new model which will soon be produced in large series—the A-15 of 450 h.p., greatly reduced in size from previous models, light and accessible.

We have also the SPA of the well-known automobile factory by that name, which, with some important changes and only a slight increase in weight, has developed her old 220 h.p. motor into a new 300 h.p. motor without being obliged to change her former equipment and machinery. These motors are already being turned out in large series.

Another important factory, the Isotta-Fraschini, produces high-grade machines. Here, again, a new motor is ready, the I.F.V.-6, developing 300 h.p.

The following figures will give an idea of Italy's effort in the production of

aviation motors, 1,500 motors a month being the present output. Before the end of the year we shall certainly produce over 2,000 motors monthly, which means 24,000 aviation engines per year, and all of them of Italian design and construction, and all of high repute. (Capt. G. Bevione, " Aerial Age Weekly," Sept. 2, 1918.)

The D.H.5 Pursuit Biplane.

This machine, made by the Darracq Motor Engineering Co., London, is a tractor biplane with a single pair of interplane struts on each side and with the wings set at a negative stagger of 0.695 m. The principal dimensions, etc., are given as under:—

Wings.

Span, 7.84 m.
Chord, 1.375 m.
Dihedral, 172°.
Angle of incidence, upper wing, 2°, amidwings, 2-1/2° at tip; lower wing 2-1/2° throughout.
No sweepback.
Wing spars of spruce and of I-section.
Ribs spaced 280 to 350 mm. apart.

Body.

Ordinary four-longitudinal type, braced by cross wiring and strengthened in front, up to pilot's seat, and at rear near tail by 3 mm. plywood. Body faired to approximately circular section near front.

The undercarriage is of V-type with solid streamlined wooden struts and a continuous axle. The tail plane is of one piece mounted at 1° incidence, without the customary incidence-change gear.

The power plant consists of a 110 h.p. rotary Le Rhone, with main fuel tank for 100 lit. of gasoline and oil tank capacity of 21 lit. There is an emergency gravity fuel tank of 26 lit. capacity on upper starboard wing. The engine is fed from main tank by compressed air generated by small air pump. Total fuel supply for two hours' flight.

The following instruments are mounted in the pilot cockpit: To right, two fuel supply pipes with stop cocks, and a change of gear for elevator control; on instrument board, tachometer, speedometer, altimeter, spark switch, watch and compass; to left, fuel and oil throttles and a hand pump for the air.

The weight of the machine is: Empty, 461 kg., and fully loaded, 694 kg. Wing area is 20.14 sq. m., wing loading 344 kg./sq. m. and power loading 5.33 kg./h.p.

A photograph and several dimensional sketches are given of the machine and also a dimensional sketch of the wing section. (" Aviation," Sept. 15, 1918.)

Aeroplane Engine Test Apparatus.

This is an advertisement of an arrangement devised by Dipl. Ing. Ed. Seppeler. A photo-reproduction of the apparatus is shown. The engine is carried on a frame, the angle of which to the horizontal can be varied. No description is given. (" Automobil u. Flugtechnische Zeitschrift der Motorwagen," Sept., 1918.)

New Aeroplane Spark-Plug.

The Research Department of the Coors-Chemical Porcelain Company in the United States is now concentrating on a new porcelain spark-plug for aeroplanes. The object sought is a spark-plug that will stand fifty hours' continuous working,

besides being capable of resisting hard knocks, and possessing some other qualities desirable in spark-plugs. Present indications point to its immediate appearance on the market. The best porcelain aeroplane spark-plugs now in use are good for about thirty hours.—(" Chemical and Metallurgical Engineering," Sept. 27, 1918.)

The Structure of the Atmosphere.

In the course of his paper Dr. K. Schütt refers to an investigation by A. Wigand, who took samples of air at various heights from 1,500 to 9,000 metres, and established an increase in the proportion of hydrogen with increase of height and a decrease in the proportion of carbon dioxide. On the basis of this investigation, the following figures are given for the percentage of hydrogen in the atmosphere at 0.20, 50, and 100 km., 0.01, 0.05, 3.72 and 97.84. The subject discussed in greatest detail is the nature of the layer which acts as an electrical conductor and guides " wireless " waves round the globe. A proposal to determine the height of this layer by projecting electric waves obliquely upwards and finding where they return to earth is mentioned with the comment that it will not be possible to carry it out during the war. (" Bulletin Aero-Club Suisse," Aug., 1918.)

Meteorological Kites.

The principal modes of exploration of the upper air are those involving the use of free balloons, of captive balloons and of kites. The latter system is said to be still in operation in Germany, but it has apparently been dropped in France. M. Frantzen urges the desirability of developing it vigorously.

As compared with the free balloon, the kite has the advantage that the instruments it carries give a continuous record of the conditions in a single locality and by the use of electrical connections the record can be made available at once. Kites of suitable construction will fly at heights from two to three kilometres which cannot be reached by kite balloons or " sausages." The creation of a kite centre (Centre Cervoliste) has been demanded in the name of the societies which are said to have obtained in peace time better results, meteorologically speaking, than all the military organisations have secured during the war. Only specialisation will give to scientific and military kites their place in the dominion of the air. (L. P. Frantzen, " L'Aerophile," Sept. 1-15, 1918.)

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The Parachute in Germany. Illus. ("Flight," Oct. 24, 1918.)

The Structure of Gusts. Major C. C. Turner, R.A.F. ("Aeronautical Journal," Sept., 1918.)

ABRIDGMENTS OF RECENT PATENT SPECIFICATIONS (AERONAUTICS).

COMPILED BY MR. H. T. P. GEE, PATENT AGENT.

118,472. Aeronautical Instrument Co. and G. Brewer, 33, Chancery Lane, London. September 10, 1917.

Aerostats; Captive Balloons.—A kite balloon is provided with only two fins communicating with the interior of the balloon so that their form is maintained by gas pressure. The interior of the fins may be stayed, and rigging may be secured to the outside to enable the fins to be pulled down against the balloon when stored and to assist in securing the balloon. According to the Provisional Specification, the fins have an angle of incidence of 5 or 6 degrees.

118,474. Aeronautical Instrument Co. and G. Brewer, 33, Chancery Lane, London. September 11, 1917.

Aerostats.—Kite balloons and non-rigid airships are provided with elastic tension springs extending in a plane across the balloon so as normally to draw in the envelope, expansion of the gas distending the envelope. The springs are laced through interior rigging bands and are arranged in a plane passing through the axis of the balloon or in planes not more than one quarter the diameter of the balloon above or below the axis.

118,500. A. F. Hawksley, Fairhaven, Lytham, Lancashire. October 16, 1917.

Shock of Landing, Deadening.—The wheel axle or the transverse member supporting the floats of an aeroplane is secured to the chassis by disks or radially placed ribbons or cords of rubber in tension which allow movement in any direction. The drawings show disks of rubber secured to a flanged sleeve surrounding the axle and to an oval frame having a central flange. The disks may be dished or flat, or both forms may be used together, and their edges and centres are strengthened by canvas vulcanised to the rubber, or a bead may be formed by a strip of rubber, cord, wire, etc., moulded in or vulcanised to the edges. Each disk may be formed in two parts to enable it to be placed in position without removing the wheel. The frame may have sockets to receive the struts of the chassis, and the frames on the two sides of the machine may be connected by struts or ties. Plates or collars may limit the lateral movements of the axle. Where rubber cords or ribbons are employed, they are stretched radially between the sleeve and frame. Blocks of rubber may be placed between the sleeve and frame to act as additional buffers when landing shocks are excessive. The bearings may be placed on one or both sides of each wheel.

Cars.—The pilot's seat may be mounted on transverse bars similarly supported.

118,514. J. H. McClellan, 564, Gilmour Street, Peterboro', and C. Selby, 104, Gore Street, Kingston, both in Ontario, Canada. November 13, 1917.

Parachutes.—A parachute, normally folded on an aeroplane, is released by the pilot when the aeroplane is stalled, whereupon the parachute opens and tends to counteract the sinking of the nose of the machine. The parachute is hinged, and when released by means of a cord is forced upwards by a spring.

118,655. H. Knudsen, 49, Thrale Road, Streatham Hill, London. August 2, 1917.

Wire Couplings, etc.—For joining a wire or wire cable to a shank-piece on an eye or a turnbuckle for use on aeroplanes, etc., the end of the wire is inserted in a hole in the shank and the joint compressed to cause the parts to become corrugated, the external surface being then given any desired form or screw-threaded. The drawings show a stay wire connected to the shank of a turnbuckle, the shank being turned to cylindrical form after the parts have been corrugated. Multiple wires may be connected to a single fitting by this method. The corrugations may be formed in two planes. To take a streamlined wire, a cylindrical hole may first be formed and the shank pressed until the hole is of the required form.

118,659. A. E. Downing, 81, Lodge Road, West Bromwich. August 28, 1917.

Aerial Machines without Aerostats; Propelling.—An aeroplane with fixed planes is propelled by a reciprocating wing carried by arms pivoted to frames, pivoted and actuated by means of a piston and cylinder supplied with air or gas from a compressor driven by an engine. The air enters the cylinder by a valve, and moves the piston downwards until the valve is closed by a cam and an exhaust valve is opened by another cam, whereupon the piston is returned by the action of elastic "muscles" arranged longitudinally within the body and extended during the down-stroke, the valve being then closed by a cam and the first-mentioned valve reopened by a cam. The piston rod bears on a T-lever which bears on levers connected by cables to small pulleys integral with large wheels, which are connected by cables to the upper and lower extremities respectively of the wing frames and carry the above-mentioned cams. The "muscles" are connected to arms of the levers, these arms being connected by cables to the wheels. The "muscles" are further connected to levers, some of these levers being connected by cables to the arms, and the other levers being connected by cables to the wing. Cables connected to pedals allow the pilot to actuate valves when desired.

118,683. H. C. Cleaver, Tudor Works, Park Royal, Willesden, London. September 8, 1917.

Screw Propellers.—Two-bladed laminæ for assembly as screw propellers are constructed of multiple parts with edge-to-edge diametrical or diagonal glue joints. A large number of modifications are described, the principle being that when the laminæ are not sufficiently wide to give the requisite strength at the hub, additional pieces are fitted. These laminæ are assembled fanwise. In constructing four-bladed propellers, the laminæ are sometimes crossed with hub-pieces. The Specification also describes keys for the laminæ, examples being shown. One figure shows a number of laminæ with keys, the joints being in staggered relationship.

118693. G. de Feure, 204a, Gloucester Terrace, Paddington, and A. A. Embiricos, 6, Crosby Square, both in London. September 17, 1917.

Aerial Warfare; Aerial Machines without Aerostats; Propelling; Planes, Construction of; Cars and Cabins.—The main plane of an aeroplane is made of sufficient depth at its middle part to enclose the forward portion of the fuselage and the motors and accessories between its upper and lower surfaces, but is of normal thickness at the tips. The drawings show a biplane having the upper plane made with a deep middle portion so as to enclose the fuselage, the motors for the propellers, the seats, etc. Four propellers are arranged, two in front and two behind the plane, and are each coupled to a separate motor. A semi-spherical front portion of the plane accommodates an observer. One figure shows the application to a triplane, in which the middle plane encloses the motors, etc., the

depth of the planes being reduced at the rear edge immediately in front of the propellers. The propellers may be mounted in gaps provided in the middle plane. A turret is provided for the pilot between the two upper planes.

Planes, Arrangement of.—The middle plane of the triplane may be merely made of sufficient span to enclose the motors.

Aerial Warfare.—The enlarged central part of the plane is provided on top with a front gun, rear gun, and lateral guns, and at the underside with a rear gun. A chamber is also provided for bombs. In the triplane there are also provided a gun, and another gun at the periphery of a hole formed at the top of the turret.

118,714. G. J. Ayling and G. Ayling, Riverside, Putney, London. October 6, 1917.

Aeronautics; Framework.—Girders, spars, struts, etc., for aerial machines are constructed of laminations of wood with the grain running in different directions, the outer laminations being of the complete length of the girders, etc., and the inner laminations of different lengths spliced together with the splices at different positions. The drawings show a spar or strut of outer laminations and inner laminations spliced. The spar, etc., may be hollow throughout, or may be hollowed at intervals.

118,739. J. I. Hall, 58, Burton Road, Kingston-on-Thames, Surrey, and Callender's Cable and Construction Co., Hamilton House, Victoria Embankment, London. November 9, 1917.

Alighting Indicators.—To facilitate night landings, an aerodrome is provided with two concentric rings of glazed lights let into the ground, the surfaces of the inner lights being inclined towards the centre of the circle, where the ground is raised to the level of the inner edges. Any one of the outer lights is illuminated to indicate the direction of the wind, and the pilot flies over it when about to alight. The inner lights are all illuminated, so that the pilot can estimate his height by observing the appearance of the ring. All the lights are neutral tinted, but by using coloured lamps in the lights adjacent to the guiding-light in the outer ring, the force of the wind may be indicated.

118,769. F. A. Jennings, Greenbank, Marlborough Hill, Harrow, Middlesex. January 4, 1918.

Wire Strainers.—A wire or like strainer, particularly adapted for aeroplane and like stay wires, comprises a right and left handed screw engaging with nuts formed with trunnions, which are passed through holes formed in metal stampings. The trunnion ends are riveted over to secure the stampings together to form the shackle, but not so as to prevent rotation therein.

118,839. J. Bouteille, 40, Rue Poussin, Paris. June 26, 1918. Convention date, June 26, 1917. Not yet accepted. Abridged as open to inspection under Sect. 91 of the Act.

Internal Combustion Engines; Regulating.—In engines for aircraft, etc., the compression is maintained substantially constant at all altitudes by rejecting portions of the charges during the compression strokes. In a four-stroke cycle engine having the usual admission and exhaust valves, portions of the charges are rejected through a cam-actuated valve to a chamber having an automatic outlet valve which delivers into the inlet pipe. A single chamber may serve several cylinders.

118,859. E. R. Calthrop, Eldon Street House, Eldon Street, London. June 12, 1917.

Parachutes.—In parachutes of the kind normally nested in a container and launched therefrom by application of the load, for example as described in Specification 21312/14, the mouth of the parachute is arranged to be automatically expanded as it issues from the container by detachably-arranged spring sectors. The spring sectors comprise normally straight springs adapted to be threaded through eyelets on the parachute and to be bent into circular form and nested within the container. When the load is applied, the springs straighten out and, in so doing, release the eyelets. Readily fracturable threads may be arranged across the mouth of the container, which has a central projection to facilitate folding the parachute. The springs may be attached to rigging tapes or by cords to the container.

118,860. E. R. Calthrop, Eldon Street House, Eldon Street, London. June 12, 1917. Addition to 8649/15.

Parachutes; Springs.—In parachute suspension ropes having a spring device interposed as described in the parent Specification, the rope is constructed so as to obviate any tendency to spin or twist when under load, and the rubber strands forming the spring device are twisted together in opposing spirals. The rope is formed of plaited or braided strands of fibre, hemp, etc., and may be solid or composed of tubular portions surrounding a solid core; or it may consist of lengths of webbing stitched together, or two ordinary oppositely-laid ropes connected together at intervals may be used. The drawings show the spring device comprising two opposite spirals of rubber strands arranged so that the outermost strand at the top is the innermost strand at the bottom, so that the strands are of equal length. In a modification, two series of strands are arranged in opposing spirals between metal caps. The ropes are connected to the spring device by bowline knots enclosed in rubber sleeves to prevent slackening.

118,931. D. J. Mooney, 48A, Gillingham Street, London. October 27, 1917.

Planes, Construction of.—The leading and trailing edges of the planes and control surfaces of aircraft are made up of thin metal bent to channel form and strengthened by corrugations, embossments and inwardly-turned edges. The ribs may be secured in outwardly-bent portions or in the corrugation.

119,043. A. V. Roe, Avro Aeroplane Works, Newton Heath, Manchester. December 2, 1916.

Gun Mountings.—Relates to mountings especially for use on aircraft and comprising an arm carrying the gun at one end and pivoted at the other end on horizontal trunnions on a bracket carried by a ring with rollers adapted to be trained around a base ring. According to the invention, the arm is arranged to turn about the horizontal trunnions with a very full travel. The gun is connected to the arm by a universal joint, and the arm is forked and pivoted on the trunnions which are carried by a bracket movable on the training ring. Bands on drums for clamping the trunnion bearings are actuated by eccentrics and a handle, which serves also to clamp the training ring to the base ring by means of a cam and wedge. The weight of the gun about the trunnions is balanced by the tension of rubber bands, each of which is connected by a pair of straps to opposite points of drums on the trunnions. The tension of the bands is adjusted by screws.

119,161. C. Bates, 73, Major Road, Stratford New Town, London. December 13, 1917.

Propelling.—A hood or casing adapted to be collapsed or to be extended to

surround the propeller comprises a number of sections sliding on rods and actuated by means of connections leading to the pilot. In modifications, the casing may consist of telescoping tubes, or of annular bodies connected together by fabric.

Steering.—The connections may be operated by means of the usual joy-stick.

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